Physical

Chemistry 2

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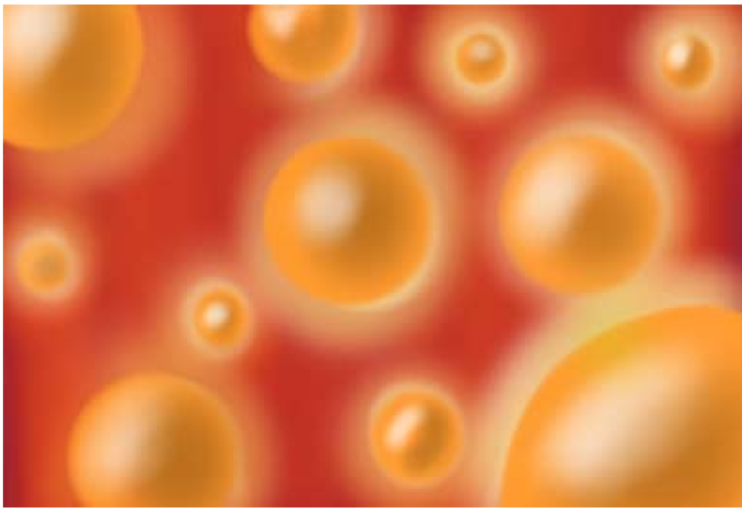

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I. Physical chemistry 2

II. Prerequisite Courses or Knowledge

Prior to tackling this module the learner must be familiar with the following concepts covered in Module 2 and 3: chemical thermodynamics, chemistry of solutions and redox reactions. The learner must be able to

- Distinguish among different solution terminologies such as saturated and supersaturated solutions
- Explain the factors affecting solubility and rate of solution
- Explain colligative properties of solutions and calculate related problems
- Distinguish among the different units of concentration and use them in relevant calculations
- Differentiate between exothermic and endothermic processes
- Carry out stoichiometric calculations involving heat changes
- Explain the concept of enthalpy and carry out calculations related to it
- Predict both qualitatively and quantitatively the spontaneity of physiochemical processes based on enthalpy, entropy and Gibbs free energy
- Write balanced redox reactions, carryout experiments and calculations related to redox reactions

III. Time

120 hours

	Topic	**Approximate Time (hours)**
Unit I	Solutions	20
Unit II	Colloids	15
Unit III	Equilibrium of phases	15
Unit IV	Electrochemistry	20
Unit V	Introduction to nuclear chemistry	30

IV. Material

Internet connectivity is essential to successfully complete this module for the purpose of

- accessing of learning activities online
- online assessment in form of quizzes, tests, assignments and experiments
- multimedia interaction (including video conferencing)
- e-Library and data base utilization
- interactive group discussions/chat sessions
- access to a library and self-study centre
- access to recommended textbooks and reference materials (web-based learning Materials)

V. Module Rationale

The module, Physical Chemistry 2, focuses on five (5) areas of physical chemistry important to many aspects of our lives: solutions, colloids, phase equilibrium, electrochemistry and nuclear chemistry. Solutions are often necessary to facilitate many chemical reactions in life processes or industry while colloids find extensive applications in industries (for pharmaceuticals, food and beverages, paints, adhesives, cosmetics, inks and many others). The applications of electrochemistry are wide spread with great economic significance. A number of life processes also involve electrochemical reactions. Many substances exist in more than one physical state, the most common being solid, liquid and gas. Each of the phases has significantly different physical properties. Knowledge of electrochemistry allows us understand certain biological processes. Rusting of iron, bleaching of stains and photosynthesis are examples of such reactions. Although nuclei of many isotopes are stable, some are unstable and will undergo what are known as nuclear reactions. Such reaction may be useful as in power generation or nuclear medicine but also dangerous as the case in weapons of mass destructions – nuclear weapons.

VI. Content

6.1 Overview

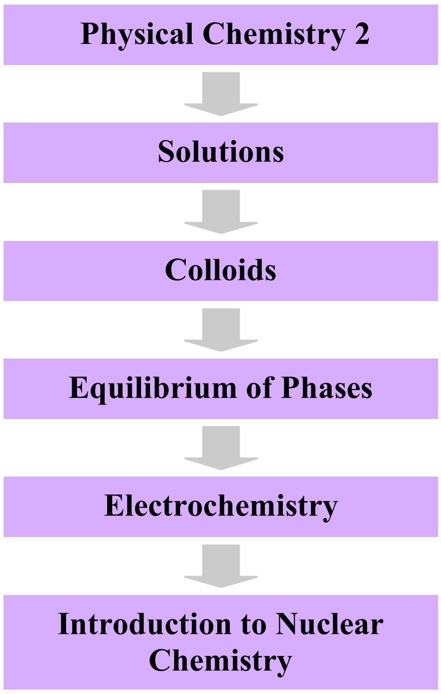
This module develops upon the concepts introduced in the module Physical chemistry 1, which focused on kinetic molecular theory, thermodynamics and chemical kinetics. It covers the study of solutions and colloids, phase equilibrium, electrochemistry and nuclear chemistry. In solutions, we examine essentially the behaviour of homogenous mixtures involving pure substances. We shall also look at colloids, which differ from solutions only in terms of sizes of the solute. The topic of phase equilibrium looks at the physical transformation of pure substances. Ideas of energy and entropy will be applied to the physical equilibrium among the phases of one or more pure substances under different conditions of temperature and pressure. In electrochemistry, we focus on chemical systems that involve the transfer of electrons or charged species i.e. oxidation-reduction reactions. Nuclear chemistry looks at processes that are associated with the nucleus. Nuclei of certain isotopes are unstable and undergo spontaneous decay emitting ionising and non-ionisation radiation. We shall examine why certain nuclear processes occur and how such processes can be harnessed for peaceful applications.

6.2 Outline

Unit I	**Solutions**
(20 hours)	Types of solutions
	Physical properties of solutions
	Intermolecular forces and the solution process
	Ideal solutions
	Temperature and pressure effects on solubility
	Colligative properties
Unit II	**Colloids**
(15 hours)	Classification of colloids
	Preparation and purification of colloids
	Stability of colloids
	Properties of colloids
Unit III	**Equilibrium of phases**
(15 hours)	Component
	Degrees of freedom
	Gibbs phase rule.
	Phase diagrams
	Multi-component systems

Unit IV	**Electrochemistry**
(20 hours)	Electrochemical cells Electrode potentials Free energy and cell potential
Unit V	**Introduction to nuclear chemistry**
(30 hours)	Phenomenon of radioactivity Rate of radioactive decay Nuclear Stability Interaction of radiation with matter

6.3 Graphic organiser



VII. General Objective(s)

On completion of this module the learner must be able to:

- Explain the driving force to the solution processes
- Explain the effect of temperature and pressure on solubility
- Provide a thermodynamic explanation to the phenomenon of mixing
- Define and explain colligative properties of solutions
- Define and classify the colloid state
- Explain factors that influence colloidal stability
- Draw and explain simple phase diagrams
- Use the concept of redox reactions to explain electrochemical reactions
- Predict the spontaneity of a reaction given the standard reduction potentials
- Use the cell potential to determine the equilibrium constant of a reaction
- Explain the radioactivity phenomenon
- Explain why some elements are stable and others are not
- Carryout calculations related to the radioactivity phenomenon

VIII. Specific Learning Objectives (Instructional Objectives)

Unit	**Learning objective(s)**
Solutions	On completion of this Unit, the learner should be able to: • Define and explain the nature of solutions • Identify and distinguish the different types of solutions • Predict whether two substances will mix to form a solution by comparing the intermolecular forces involved • Understand and explain the effects of temperature, pressure and polarity of solvent/solute on solubility • Account for the colligative properties of solutions and perform calculations involving these properties

Unit	**Learning objective(s)**
Colloids	On completion of this Unit, the learner should be able to: • Describe the properties of colloidal systems • Differentiate the different types of colloidal systems • Explain factors affecting the stability of colloids • Describe and explain the different properties of colloids such diffusion, osmosis, viscosity and electrical properties
Equilibrium of phases	On completion of this Unit, the learner should be able to: • Explain concepts of vaporization, boiling, vapour pressure, and how these are affected by variables of temperature, pressure and will be able to interpret phase diagrams • Be able to calculate all relevant quantities in binary equilibrium phase diagrams: number of phases, composition of phases • Interpret the Gibb's **phase** rule.
Electrochemistry	On completion of this Unit, the learner should be able to: • Explain and describe an electrochemical cell • Represent voltaic cells diagrammatically and in short notation • Use the concept of reduction potentials to explain reactions taking place at the anode and cathode • Explain and use reduction potential to predict spontaneity of chemical reactions • Relate the emf to Gibbs free energy and carry out related calculations
Nuclear Chemistry	On completion of this Unit, the learner should be able to: • Explain and describe the nature of radioactivity • Identify the different types of radioactive emissions and the properties of the emitted radiation • Carry out calculations using the radioactive decay law • Explain the relation between mass and energy and solve problems relating to mass-energy equivalence

IX. Teaching And Learning Activities

9.1 Pre-assessment

Pre-assessment on the understanding of fundamental principles: for solutions and colloids, phase equilibria, electrochemistry and nuclear chemistry.

Rationale

For the learner to complete this module successfully, prior requisite knowledge is necessary. This pre-assessment allows the learner to know how prepared there are for the topics likely to be encountered. The questions are an evaluation of knowledge previously acquired such as principles of solutions, balancing redox reactions and thermodynamics. These questions relate to concepts that are key to understanding solutions, phase equilibria, reactions that involve charge transfer and subatomic level reactions.

Questions

1. Which of the following substances exerts the highest pressure? Give reason(s) for your answer.

   (a) 1 mole N_2 at 273 K in 11.2 dm^{-3}
   (b) 1 mole N_2 at 300 K in 22.4 dm^{-3}
   (c) 1 mole H_2O at 300 K in 1 dm^{-3}
   (d) 1 mole C_4H_{10} at its normal b. pt

2. How would you expect the substances given below to behaviour in the solvents indicated i.e. low or high solubility?

   (a) HCl in H_2O
   (b) HF in H_2O
   (c) S_8 in H_2O.
   (d) $NaNO_3$ in hexane, C_6H_{14}

3. Consider the following two sets of mixtures (a) water mixed with methanol, obeys Raoults law and (b) water mixed propan-1-ol, which forms an azeotropic mixture. With the information given draw suitable schematic diagrams to illustrate their behaviour using a vapour pressure/composition curves.

4. Given the following information for ammonia

b. pt	240 K
m. pt	195.0 K
triple point	194.9 K

draw a sketch diagram to illustrate the phase changes, highlighting significant points.

5. Balance the following redox reaction using the ion-electron method in acidic medium.

$$Br^- (aq) + MnO_4^- (aq) \leftrightarrows Br_2 (g) + 2Mn^{2+}(aq)$$

6. When 193 C of electricity are passed through a molten metal, 1.0 x 10^{-13} mol of atoms are deposited at the cathode. What could be the metal deposited at the cathode.

(a) Cu (b) Pb (c) Ag (d) Zn

7. Which of the following represent non-particulate radiation?

(a) alpha (b) beta (c) neutron (d) gamma

8. Which element in Group 18 is naturally radioactive and has no stable isotopes?

Which element in Group 18 is naturally radioactive and has no stable isotopes?

(a) Ar (b) Kr (c) Xe (d) Rn

9. Consider the following reaction shown below

$${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + \text{energy}$$

What process does the reaction above represents?

(a) fission
(b) fusion
(c) artificial transmutation
(d) alpha decay

10. In how many days will a 12-gram sample of decay, leaving a total of 1.5 grams of the original isotope? (The half-life of $^{131}_{53}\mathrm{I}$ is 8.07 days).
    (a) 8.0
    (b) 16
    (c) 20
    (d) 24

Answer Key

1. The solution to the problems takes into accounts the properties and state of the substances in relation to pressure. The substances in (a) and (b) are gases. A comparison of the pressures can be made by calculation using *pV = nRT*.

    (a) $P = \dfrac{1\,\mathrm{mol} \times 8.314\,\mathrm{J\,mol^{-1}\,K^{-1}} \times 273\mathrm{K}}{11.2 \times 10^{-3}\,\mathrm{m^3}} = 2.02 \times 10^5\,\mathrm{Pa}$

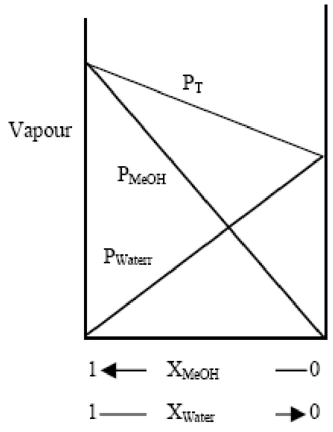
    (b) $P = \dfrac{1\,\mathrm{mol} \times 8.314\,\mathrm{J\,mol^{-1}\,K^{-1}} \times 300\,\mathrm{K}}{22.4 \times 10^{-3}\,\mathrm{m^3}} = 1.11 \times 10^5\,\mathrm{Pa}$

    (c), (d) These are liquid at the given temperature and pressure. In the case of (d) at its normal b.pt the vapour pressure is 1.01 x 10^5 Pa.

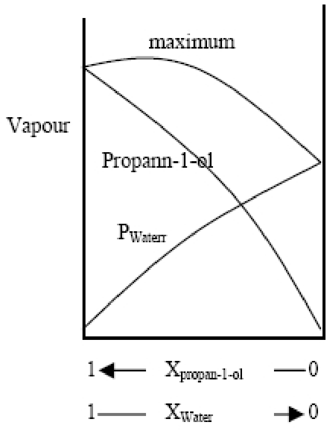
2. (a) Since both are polar covalent molecules solubility is high
    (b) Since both are polar covalent molecules capable of forming hydrogen bonds the solubility will be high.
    (c) Low solubility is expected since S_8 is a nonpolar covalent molecule being put in H_2O which is very polar.
    (d) The solubility is expected to be low since $NaNO_3$ is an ionic solid and C_6H_{14} is a nonpolar solvent.

3.

(a)



(b)



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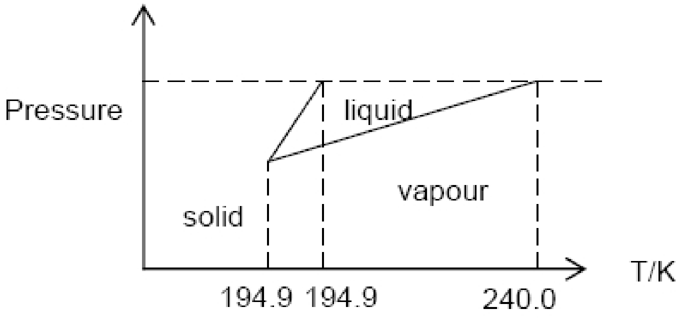


5. The solution is reached by following the steps.

Step 1: Assign oxidation states

$Br^- (aq) + MnO_4^-(aq) \leftrightharpoons Br_2 (g) + 2Mn^{2+}(aq)$

-1 +7(-2)+4 0 +2

Step 2: Balance atoms other than O and H in the half reactions

$2Br^- (aq) \rightarrow Br_2 (g)$ *oxidation reaction*

$MnO_4^-(aq) \rightarrow Mn^{2+}(aq)$ *reduction reactions*

Step 3: Balance the O and H

$2Br^- (aq) \rightarrow Br_2 (g)$

$MnO_4^-(aq) + 8H^+ \rightarrow Mn^{2+}(aq) + 4H_2O$

Step 4: Balance charges

$2Br^- (aq) \rightarrow Br_2 (g) + 2e^-$

$MnO_4^-(aq) + 8H^+ + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O$

Step 5: Balance the electrons

$5 \times [2Br^- (aq) \rightarrow Br_2 (g) + 2e^-]$

$2 \times [MnO_4^-(aq) + 8H^+ + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O]$

gives us

$10Br^- (aq) \rightarrow 5 Br_2 (g) + 10e^-$

$2MnO_4^-(aq) + 16H^+ + 10e^- \rightarrow 2Mn^{2+}(aq) + 8H_2O$

Step 6: Add up the half reaction

$$2MnO_4^-(aq) + 10Br^-(aq) + 16H^+ \longrightarrow 2Mn^{2+}(aq) + 5\ Br_2\ (g) + 8H_2O$$

6. We start by calculating the number of electrons passed knowing that and the electrical charge per mole of electrons which is Faraday's constant, F = 96 485 C/mol e^-.

$$\frac{193\ C}{96\ 500\ C\ mol^{-1}} = 2 \times 10^{-3}\ mol^{-1}$$

Thus the charge on the metal is $\frac{2 \times 10^{-3}\ mol^{-1}}{1 \times 10^{-3}\ mol^{-1}} = +2$

The metal could be Cu/Cu^{2+}, Pb/Pb^{2+} or Zn/Zn^{2+} but not Ag^+.

7. (d) gamma

8. (d) Rn

9. (b) fusion

10. Radioactive decay follows first order kinetics for which

$t_{\frac{1}{2}} = 8.07$ days

The decay constant, λ, is calculated, from

$$t_{\frac{1}{2}} = 8.07\ \text{days} = \frac{0.693}{\lambda}$$

$\lambda = 0.086\ day^{-1}$

Using the integrated rate equation

$$\ln\frac{1.5}{12.0} = -\ 0.086 \times t$$

Solving for t, t = 24 days

Pedagogical Comment For Learners

This pre-assessment is intended to gauge the learner's readiness to study this module and successfully complete it. The assessment covers foundation principles such as those that relate to intermolecular forces and balancing of redox reactions, which you will come across in this module. Evaluation of concepts that may be new to the learner, for example balancing nuclear reactions, are included. The learner who scores less than 60 percent is well advised to check the Section of pre-requisite course or knowledge and revisit the concepts.

X. Learning Activities

Learning activity # 1

Title of Learning Activity: Solutions

Specific learning objectives

When you have completed this activity, you should be able to

- Define and explain the nature of solutions
- Identify and distinguish the different types of solutions
- Predict whether two substances will mix to form a solution by comparing the intermolecular forces involved
- Understand and explain the effects of temperature, pressure and polarity of solvent/solute on solubility
- Account for the colligative properties of solutions and perform calculations involving these properties

Summary of the learning activity

Solutions are important to many chemical processes. Indeed very often in order for chemical reactions to take place, reacting species have to come into intimate contact. Many substances in nature are found in form of solutions, which are homogeneous mixtures comprising a solvent and a solute. In this unit we shall study the behaviour and properties of solutions. The factors that favour the formation of solutions will be examined to enable one predict whether a particular mixture will mix to form a solution or not. What role do the intermolecular forces play in the formation of a solution? What is the effect of temperature and pressure on the solubility of a substance? How can we use thermodynamics to explain and predict the formation of a solution? This Unit will seek to answer these and other questions related to solutions. Finally, properties of a solution that depend significantly only on the presence of a solute, colligative properties, such as osmosis, freezing point depression and boiling point elevation will be studied. The learner will use the knowledge gained to perform calculations related to these properties.

List of required readings

- Solutions
- Solutions Wikipedia

List of relevant useful links

Concepts of Chemistry

http://www.wpi.edu/Academics/Depts/Chemistry/Courses/General/conceptt.html

Chem1 Virtual Text Book

http://www.chem1.com/acad/webtext/virtualtextbook.html

List of relevant MULTIMEDIA resources

Multimedia Resources

- Computer with internet connectivity to enable access to open source learning materials and interactive learning through email, video conferencing and use of CD-ROMs
- QuickTime Movie Player Software
- Shockwave Player Software
- Macromedia Flash Player Software

Detailed description of the activity

This learning activity shall begin by examining the nature of a solution, the question of what is a solution. You will then proceed to look at the different types of solutions that exist and what factors favour the formation of a solution. The energy change involved in the solution process will be used to predict if substances mix to form a solution or not. You will also learn how the presence of solute affects physical properties of a solution such as the vapour pressure, boiling and freezing point.

Formative evaluation

- As you make your way through this learning activity you will come across problems to test your conceptual understanding of the subject matter
- Rapid quizzes are provided to check your understanding
- Practical experiments will be given to evaluate your understanding of theory-practice relations
- Simulated experiments/exercise will give to test your understanding of certain concepts

Solutions are important in that many chemical reactions occur in solutions. In order for a chemical reaction to occur, molecules must come into contact. Solutions allow intimate contact of molecules of different types thereby facilitating chemical reactions. The study of solutions is important as most reaction, be it in the laboratory, industry or life systems take place in solution. They also provide a convenient and accurate means by which we can introduce small quantities of a substance to reaction systems. When a substance goes into solution, existing attractive forces are broken new ones formed between the dissolved solid substance, and for example, the liquid. The intermolecular forces between the solute and solvent molecules influence the properties of a solution. The physical properties of solutions largely depend on the concentration of the solute than the identity. Such properties are known as colligative properties and are useful in determination of molar masses of large molecules. Several biological processes are based on colligative properties of solutions for example; osmosis is the principle behind kidney dialysis.

1.1 What is a solution?

A solution is a homogeneous mixture of two or more substances. The substances may be in the gaseous, liquid or solid state. A homogeneous mixture is a physical mixture of two or more pure substances whose distribution is uniform throughout. When a solution forms the molecules of the solute are discrete and mixed with the molecules of the solvent. The major component is known as the solvent whilst the minor is the solute. Intermolecular forces exist between the solvent and solute molecules. Although we usually think of solutions as being liquids they may actually be a mixture of a gas, liquid or solid solute in a liquid or as gases and solids.

1.2 What is the driving force to formation of solutions?

The solution process is essentially a balance between the various energy changes taking place when a solute is introduced into a solvent. From your knowledge of thermodynamics we know that energy changes that lead to lower energy of the system tend to be more favourable. In the solution process, two steps need to be considered in terms of energy change. In the first step, the solute must be introduced to the solvent; molecules must be pulled apart before being dispersed in the solvent. This step can therefore be considered to be unfavourable to the formation of the solution. Whether dispersing of the solute is favourable or not depends on the type of solvent-solute interactions. The formation of a solution is favoured in the solvent-solute (A-B) if intermolecular forces are greater than those of the solute (A-A) and solvent (B-B). This leads to a lower potential energy state when a solution forms and hence favourable energetically. The formation of a solution is favoured if the balance in terms of energy change between the two steps is exothermic.

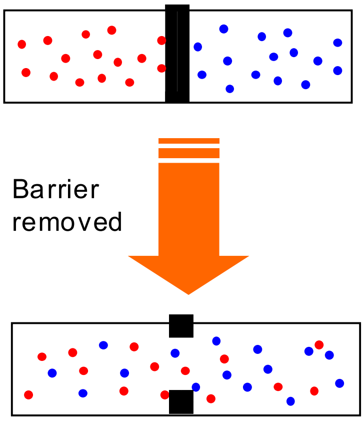


Figure 1.1 The diagram shows two gases initially separated by a barrier. Removal of the barrier leads to spontaneous mixing of the two gases

However, you recall that in our study of thermodynamics, whether there is an increase or decrease in disorder at a molecular level (entropy change) has to be taken into account. An increase in disorder favours the solution process. Spontaneous formation of gaseous solutions explains the fact that increased disorder is a strong driving force to the formation of solutions. Consider two gases initially separated into two compartments by a barrier as shown in Figure 1.1 Once, the barrier is removed the gases spontaneously mix to form a homogeneous mixture, a solution.

1.3 Types of solutions

Matter in nature is found in three states: solid, liquid and gas. Solutions can also be found in the three states of matter provided the energetics of solution formation are favourable. The table below provides a summary of the energy changes for different types of solutions.

Table 1 Table shows possible solvent-solute mixtures with the associated energy and entropy changes.

Solvent	Solute	Energy to disperse solute	Energy to dissolve (disperse solute)	Increase in disorder (randomness)
Gas	Gas	0	0	Large
Gas	Liquid or solid	Large	0	Large
Liquid	Gas	0	Varies	Decreases
Solid	Gas	0	Endothermic	Decreases
Liquid	Liquid	Varies	Varies	Moderate

Mixing of different substances, invariable brings greater disorder to the systems and is accompanied by an increase in volume. Temperature generally tends to favour increase in disorder or randomness.

Many examples of solutions involving different states of matter are abound in nature. Table 2 shows commonly encountered examples of solutions in their various states.

Table 2 Examples of different types of solutions and corresponding examples

Component 1 (solvent)	Component 2 (solute)	State of resulting solution	Examples
Gas	Liquid	Liquid	Soda water (Carbon dioxide in water)
Solid	Solid	Solid	Solder (Sn/Pb)
Gas	Solid	Solid	Hydrogen gas in Pd
Gas	Gas	Gas	Air
Liquid	Liquid	Liquid	Alcohol in water
Solid	Liquid	Liquid	Salt and water

Practice problem 1

Which of the following is a homogeneous mixture?

(a) NaCl (s)

(b) NaCl (l)
(c) NaCl (g)
(d) NaCl (aq)

1.3.1 Gases solutions

Gaseous solutions are obtained by mixing gases to form a homogeneous mixture. All gas-gas mixture are solutions of gases. The air that we breathe is a natural solution of gases comprising among others gases such as oxygen, nitrogen and carbon dioxide as shown in the Table below.

Table 3 Percent abundance of selected gases in air

Gas	Percentage (%)
Nitrogen (N_2)	78
Oxygen (O_2)	21
Water (H_2O), carbon dioxide (CO_2)	Variable

The amount of water and carbon dioxide are affected by a number of factors including temperature, weather, altitudes and several others.

The energy required in mixing of gases is very small and the increase in randomness is favoured at all temperatures. Further more gases are found to be ***miscible*** in all proportions.

1.3.2 Gas in liquid solutions

When a gas is introduced into a liquid, it is confined to a smaller volume a decrease in randomness occurs, a process that is not favoured. Thus, in order that a solution of gas in liquid forms, there must be other compensating factors. For example, if the gas reacts chemically with the solvent as the case when carbon dioxide, hydrochloric acid or ammonia, dissolves in water. Although the process of introducing these gases into a liquid results in decreased randomness, the energy changes associated with the reactions offsets the unfavourable randomness effect.

Effect of temperature on solubility of gases

The solubility of most gases decrease with increasing temperature. For example oxygen and nitrogen, two major components of air are known to decrease as the temperature increases. It is for this reason that many types of fish can only survive in cold water as opposed to warm where there are lower amounts of dissolved oxygen. Comparative data is given in Table 4 showing solubility of selected gases at different temperatures. Solubility is in grams per 100 g of water when gaseous space over liquid is saturated with gas and the total pressure is 1 atm.

Table 4 Comparative data depicting the solubility of the gases N_2, O_2 and CO_2.

Gas	**Temperature (°C)**			
	0	**20**	**50**	**100**
N_2	0.0029	0.0019	0.0012	0
O_2	0.0069	0.0043	0.0027	0
CO_2	0.335	0.169	0.076	0

The opposite phenomenon is often observed for solubility of gases in organic solvents. In this case, solubility increases with increase in temperature. For example, the solubility of hydrogen, nitrogen, carbon monoxide, helium and neon rise with increasing temperature in organic solvents such as carbon tetrachloride, toluene and acetone.

Gases become more soluble at higher pressure

A common phenomenon when one opens a can of many beverages is the fizzing sound as the gas escapes. Although the gases in air are not very soluble at room temperature, they become increasingly soluble at high pressures. The solubility of a gas is affected a lot more by pressure than temperature. To understand the effect of pressure, consider the following equilibrium for dissolution of a gas.

$$\text{Gas + solvent} \leftrightarrows \text{solution}$$

An increase in pressure on the system reduces the volume available to the gas. According Le Châtelier's principle the system must change to counter act the stress created. Consequently, the system reacts so as to reduce the pressure by decreasing the amount of gas. Gas molecules are absorbed from the gaseous phase into solution. The equilibrium in the above reaction equation is thus shifted to the right i.e. increased solubility.

If the pressure on the solution is reduced then the reverse effect in equilibrium is observed, some of the gas molecules leave the solution into the gaseous phase. Equilibrium shifts to the left of the reaction equation. Fizzing of the cola drink or any other carbonated drink is a response to the lowering of pressure as the can (or bottle is opened). The English chemist William Henry established that the solubility of a gas increased with increased pressure according to the mathematical relationship known as Henry's law.

$$C = kP_{gas} \tag{1.1}$$

The solubility of a gas in a particular solvent is represented by C, P_{gas} is the partial pressure of the gas and k is the proportionality constant. Henry's constant is unique to each gas.

Rationalization of Henry's law

In a saturated solution, the number of molecules leaving and entering the solution is equal. The rate at which molecules leave the gaseous phase into the solution and that at which the molecules leave the solution both depend on the number of molecules per unit volume. When the number per unit volume of the molecules is increased in the gaseous state, the number of molecules per unit volume in the solution also increases. When pressure is increased the number of molecules per unit volume in the solution must also increase. It is important to note, however, that Henry's law fails for gases at high pressures and if there is a chemical reaction, or when the solvent-solute interaction is significantly different from the solute-solute or solvent-solvent interaction.

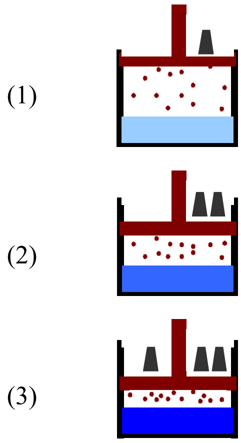


Figure 1.2 Shows the effect of pressure on the solubility of the gas. The depth of the colour is indicative of concentration of the gas

Example 2

The solubility of oxygen gas at 0 °C and 101325 Pa is 48.9 mL per litre. Calculate the molarity of oxygen in a saturated water solution when the oxygen is under its normal pressure in air of 0.2095 atm.

Solutions

The problem is solved by first determining the molarity of the saturated solution at the given temperature and pressure:

$$\text{Molarity} = \frac{0.0489\,\text{L} \times \frac{1\,\text{mol}\,O_2}{22.4\,O_2}}{1\text{L}} = 2.18 \times 10^{-3}\ \text{M}$$

According to Henry's law

$$C = kP_{gas}$$

$$k = \frac{C}{P_{gas}} = \frac{2.18 \times 10^{-3}\ \text{M}}{1\text{atm}} = \frac{C}{0.2095\,\text{atm}}$$

$$C = \frac{0.2095\text{M}}{1\text{atm}} x 2.18 x 10^{-3} = 4.57 x 10^{-4}\,\text{M}$$

Practice problem 2

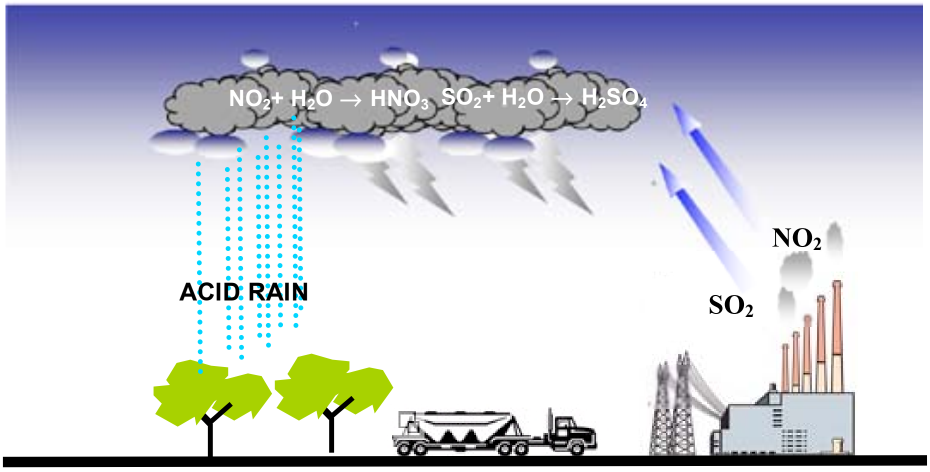
What is the equilibrium concentration (mg O_2 per L) of oxygen gas in fresh water at 25 °C when exposed to air at a pressure of 1 atm? The Henry's law constant for oxygen in water at 25 °C is 3.0 x 10^7 atm.

Visual demonstration: Forces of cohesion

1.3.3 Liquid in liquid solutions

Two liquids are more likely to form a solution if for example for species A and B, the interactions of A-A, B-B and A-B are similar. The intermolecular forces in the two liquids must be similar. For example, the intermolecular forces at play in hexane are mainly dispersion forces (weak forces due to temporary dipoles) and similarly in heptane. Thus, the intermolecular forces that would exist between hexane and heptane are also dispersion forces. These liquids should be miscible.

On the other hand if the intermolecular forces are greater in one liquid, for hexane and water, the liquids will not make a solution. Water forms strong hydrogen bonds with other water molecules. Water will tend to be miscible with liquids that can form hydrogen bonds. For example, ethanol and water are completely miscible.


$NO_2 + H_2O \rightarrow HNO_3$ $SO_2 + H_2O \rightarrow H_2SO_4$
ACID RAIN
NO_2
SO_2

Gas emissions from industries and cars such as sulphur dioxide or nitrogen dissolve in water to form acids, which adversely affects the environment.

1.3.1 Energy considerations – to mix or not to mix?

When two liquids mix, there is an increase in entropy in much the same way as when gases mix. Hence the entropy of mixing is always positive. The free energy of mixing therefore for the two liquids may be written as

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix} \qquad (1.2)$$

A negative ΔG favours mixing of the two liquids. For an ideal solution, the enthalpy change is zero and therefore mixing is solely due the positive entropy. However, mixing for some solutions may be either exothermic or endothermic. When mixing is exothermic, it works synergistically with the entropy of mixing to give a more negative ΔG. In the case where mixing is endothermic the magnitude of ΔH becomes important in determining ΔG. If magnitude of ΔH_{mix} is small i.e. $\Delta H_{mix} < T\Delta S_{mix}$ then the term $\Delta H_{mix} - T\Delta S_{mix}$ is still negative but if $\Delta H_{mix} >> T\Delta S_{mix}$, the $\Delta H_{mix} - T\Delta S_{mix}$ becomes positive the liquids will not mix.

1.3.4 Solutions of solids in liquids

Systems of solids in liquids are some of the most frequently encountered chemical solutions. In introducing the solid solute into solution, energy is required to overcome the strong intermolecular forces found in solids. How are these forces overcome? Consider the dissolution of NaCl crystal. As shown in the diagram in Figure 1.3.

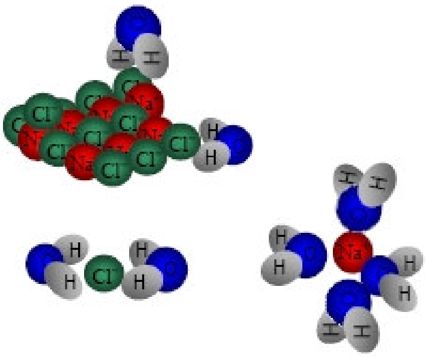


Figure 1.3 Illustration of the solution process, dissolution of NaCl.

In solution, the water molecules tend to orient themselves in such a way that the positive end of the dipoles is towards the chloride ions (Cl^-) whilst the negative ends are towards the sodium ions. The ions at the edges are less strongly held and much more easily detached from the crystal. Thus, the crystal is ‘chipped’. This continues with ions going into solution at the edges. Once freed the ions are surrounded by water molecules. We can explain the dissolution of non-polar substances in non –solvents in much the same way. In this case, the forces of attraction involved are dispersions forces.

Simulation: Solution of salt

1.4 Thermodynamics of mixing

In the topics relating to kinetic molecular theory and gases we came across a property known as partial pressure used to describe the contribution to the total pressure of each gas. Thus, for gases partial pressure describes the contribution of one component to the total pressure. To enable us discuss the thermodynamic properties of mixtures, we need to introduce a property similar to partial pressure in gases called *partial molar quantities*. Partial molar quantities depend on the amount of a particular component in a mixture. A common example to illustrate the concept of partial molar quantity is the partial molar volume. The partial molar volume of a substance A in a mixture is the change in volume when 1 mole of A is added to a large excess of the mixture. The partial molar volume of a substance A at a certain composition is defined as

$$V_A = \left(\frac{\partial V}{\partial n_A}\right)_{T,P,n_B} \qquad (1.3)$$

where V_A is the partial molar volume, n_A is the number of moles of substance A at constant temperature, pressure and constant amount of substance B. Suppose that a small amount substance A, dn_A and dn_B of B are added to a mixture, the change in volume of the mixture is given by

$$dV = \left(\frac{\partial V}{\partial n_A}\right)_{T,P,n_A} dn_A + \left(\frac{\partial V}{\partial n_B}\right)_{T,P,n_B} dn_B \qquad (1.4)$$

$$= V_A dn_A + V_B dn_B \qquad (1.5)$$

The expression becomes $V = n_A V_A + n_B V_B$ when the partial molar volumes of the two substances at a particular composition are known.

This concept can be extended to thermodynamic quantities such Gibbs energy. The partial molar Gibbs energy is also known as the chemical potential is designated by the symbol μ_i. The chemical potential is a measure of how much free energy changes (dG_i) on addition or removal of dn_i moles of 'i' substance keeping T, P and amount of any other substance constant (n_J)

$$\mu_i = \left(\frac{\partial G}{\partial n_i}\right)_{T,P,n_j} \qquad (1.6)$$

The chemical potential of a pure substance shows how the Gibbs energy of the system changes on addition of another substance.

For a pure substances Gibbs energy is given by $G = \frac{\partial(nG_m)}{\partial n}_{P,T}$

It can be shown that the free energy is related to pressure through the equation

$$G = G^\circ + nRT\ \ln\left(\frac{P}{P^\circ}\right) \qquad (1.7)$$

From which the chemical potential is

$$\mu = \mu^\circ - nRT\ \ln\left(\frac{P}{P^\circ}\right) \qquad (1.8)$$

The chemical potential therefore shows the variation of G when the amount a substance changes.

1.5 Chemical potential for a gaseous mixture

The chemical potential of a pure gas is given by the equation (1.8)

Where R is the universal gas constant, T is the absolute temperature in Kelvin and P is the pressure of the gas.

$$\mu == \mu^\circ_A + RT\ \ln\left(\frac{P}{P^\circ}\right) \qquad (1.9)$$

If another substance was to be added to the pure A, the chemical potential becomes

$$\mu == \mu^\circ_A + RT\ \ln\left(\frac{P_A}{P^\circ}\right) \qquad (1.10)$$

where P_A is the partial pressure of the gas in the mixture comprising of A and B. The chemical potential for the component B can be written similarly.

1.6 Gibbs energy of mixing

For the two components, system described earlier (Equation 1.5) the total Gibbs free energy of the two-component system is given by

$$G = n_A\mu_A + n_B\mu_B \qquad (1.11)$$

Now, consider two pure gases A and B that are placed in two separate containers with n_A and n_B moles respectively.

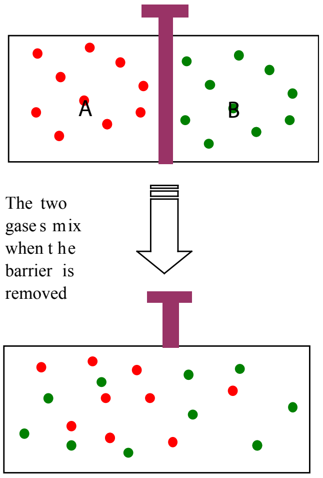


Figure 1.4 Depicting the mixing of two gases.

Before mixing, the gases have their pure chemical potential. The total Gibbs energy before mixing is the sum of the chemical potentials.

$$G_{\text{initial}} = n_A \left[\mu_A^\circ + RT \ln\left(\frac{P}{P^\circ}\right)\right] + n_B \left[\mu_B^\circ + RT \ln\left(\frac{P}{P^\circ}\right)\right] \qquad (1.12)$$

After the barrier is removed, the gases mix so that the total pressure is the sum of their partial pressure $P = P_A + P_B$. Gibbs energy is then given by

$$G_{Final} = n_A \left[\mu_A^{\circ} + RT\ \ln\left(\frac{P_A}{P^{\circ}}\right)\right] + n_B \left[\mu_B^{\circ} + RT\ \ln\left(\frac{P_B}{P^{\circ}}\right)\right] \tag{1.13}$$

The change in Gibbs free energy on mixing is the difference between the initial free energy, $G_{initial}$, and the final G_{final} i.e.

$$\Delta_{mix}G = n_A\ RT\ \ln\left(\frac{P_A}{P^{\circ}}\right) + n_B\ RT\ \ln\left(\frac{P_B}{P^{\circ}}\right) \tag{1.14}$$

The may also be written in terms of mole fractions as

$$\Delta_{mix}G = x_A RT \ln x_A + x_B RT \ln x_B \tag{1.15}$$

since $n_i = x_i n$ and $P_i/P = x_i$.

1.7 What about the entropy of mix?

The entropy of mixing is derived from the thermodynamic expression that, $-S = (\partial G/\partial T)_{P,n}$. It then follows from the equation (1.15) that the entropy of mixing is given by the expression

$$\Delta_{mix}S = -\left(\frac{\partial \Delta_{mix}G}{\partial T}\right)_{P,T,n_A,n_B} = -nR\left(x_A \ln x_A + x_B \ln x_B\right) \tag{1.16}$$

From previous discussions in thermodynamics you will recall that Gibbs energy is related to enthalpy through the expression $\Delta G = \Delta H - T\Delta S$. For the mixing of two gases we can write that $\Delta_{mix}G = \Delta_{mix}H - T\Delta_{mix}S$, which gives

$$\Delta_{mix}H = \Delta_{mix}G + T\Delta_{mix}S. \tag{1.17}$$

If the gases under consideration are perfect gases then at constant temperature $\Delta H_{mix} = 0$ from equation (1.15) and (1.16). The significance of this result is that it confirms our expectations that there are no interactions in molecules of a perfect gas.

Chemical potential of liquid mixture

The formation of a liquid-liquid solution can be viewed as involving three main steps. The first step involves the introduction of the solute liquid into the solvent. Molecules of one liquid have to be moved apart to make way for the other liquid molecules. Forces of attraction have to be overcome during this process. This process thus requires energy (endothermic) and leads to an increase in the potential energy of the system. The second step involves expansion of the solvent molecules to make way for the solute liquid. Energy is also required and similarly leads to an increase in the energy of the system. In the final step the molecules need to mix. The molecules experience mutual attraction giving off energy and decreasing the systems energy. From the preceding discussion, the net energy change is the balance when the three steps are considered. The energy diagram to illustrate the changes in energy is shown in Figure 1.5.

If the energy change (input) in steps 1 and 2 is equal to energy change (output) in step 3, the heat of solution, $\Delta H_{solution} = 0$. This signifies a condition where the inter-molecular forces in both the solute and solvent are the same. A typical example is benzene and carbon tetrachloride. The solution formed from the mixing of benzene and carbon tetrachloride approximates to an ideal solution.

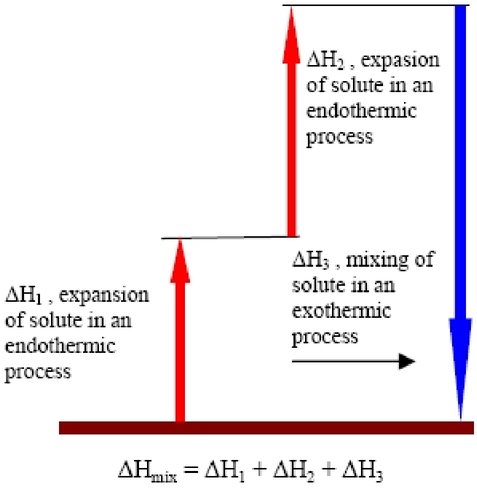

ΔH₂ , expasion of solute in an endothermic process
ΔH₃ , mixing of solute in an exothermic process
ΔH₁ , expansion of solute in an endothermic process
ΔHmix = ΔH₁ + ΔH₂ + ΔH₃

Figure 1.5 Diagram showing energy changes during the mixing of two liquids

1.8 Ideal solutions

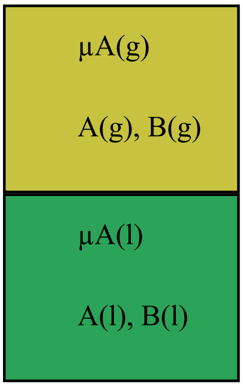


Figure 1.6 The chemical potential of the gaseous form of the pure substance A, μA(g), equals that of the pure liquid A, μA).

To consider the chemical potential of liquids we first consider the equilibrium that exists between a liquid and its vapour pressure. We make use of the fact that at equilibrium, the chemical potential of a substance in the liquid is equal to the chemical potential of the substance in the vapour. Let us consider a pure liquid A with chemical potential $\mu_A^*(l)$ with a vapour pressure P_A^* . The chemical potential for the pure liquid A can be written as

$$\mu_A^*(l) = \mu_A^\circ + RT\ \ln\left(\frac{P_A^*}{P^\circ}\right) \tag{1.18}$$

If another solute was introduced into to the liquid then the vapour pressure above is no longer that of the pure substance P_A^* but the partial pressure P_A. The chemical potential is thus given by

$$\mu_A(l) = \mu_A^\circ + RT\ \ln\left(\frac{P_A}{P^\circ}\right) \tag{1.19}$$

By combining equations (1.18) and (1.19) we obtain the equation (1.20), without the standard chemical potential of the gas.

$$\mu_A(l) = \mu_A^*(l) + RT\ \ln\left(\frac{P_A}{P_A^*}\right) \qquad (1.20)$$

Rauolt's Law

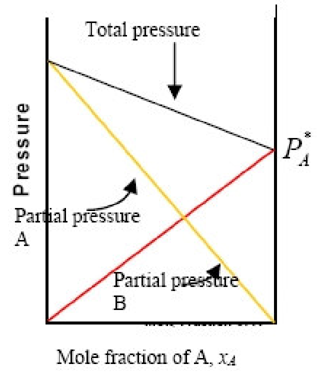


Figure 1.7 Diagram depicting the variation of vapour pressure and the partial vapour pressure of an ideal binary mixture.

Rauolt's law states that the vapour pressure of the solution P_{soln} is equal the product of the mole fraction of the solvent x_{solv} and its vapour pressure P_{Solv}°.

$$P_A = x_A P_A^{\circ} \qquad (1.21)$$

Rauolt's law

Solutions that obey Rauolt's law at all compositions of components A and B are ideal solutions. For an ideal solution therefore, where $x_A \approx \frac{P_A}{P_A^{\circ}}$ the chemical potential for the liquid becomes

$$\mu_A(l) = \mu_A^*(l) + RT\ \ln x_A \qquad (1.22)$$

which provides an alternate definition of an ideal solution.

Interactive exercise: Vapour pressure

An ideal solution is a solution in which the forces of intermolecular attraction in the two components (solute and solvent) are very similar to one another and to the forces of attraction (solvent-solute) in the solution. Ideal solutions are therefore ones for which the enthalpy of solution is zero. In other words they occur when solute and solvent are very similar-for example, benzene and toluene; hexane and heptane; pentanol and hexanol. If the forces of attraction differ in the two components and the solution, the solution is said to deviate from Raoult's law. Real solutions follow a different law known as Henry's law. William Henry found that the vapour pressure of a dilute solution is proportional to the mole fraction, x_B.

$$P_B = x_B K_B \quad \text{Henry's law} \qquad (1.23)$$

The proportionality constant K_B has pressure units and is unique for to each gas. Henry's law constant depends on temperature and the solvent/solute combination.

1.9 Colligative Properties

Colligative properties are solution properties dependent only on the amount of solute present. The particles in solutions may be ions or molecules. Colligative properties include vapour pressure, boiling point, melting point and osmotic pressure. In the section that follows we examine the effects of solutes on a liquid on the properties just mentioned.

Vapour pressure of solutions

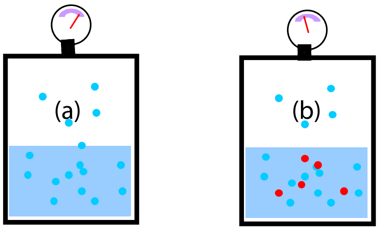


Figure 1.8 (a) Liquid-vapour equilibrium with a relatively high rate of vaporisation (b) Some solvent molecules have been replaced with solute molecules. The rate at which solvent molecules are escaping is lower. Low rate of vaporisation.

The vapour pressure of a liquid depends on the escaping tendency of the solvent molecules from the liquid phase. It is a direct measure of the escaping tendency of molecules from the liquid into the vapour phase. An increase in disorder tends to favour many processes including evaporation. The increase in disorder on entering of the gas phase is reduced when the solvent is diluted with a solute. The incorporation of a non-volatile solute reduces the escaping tendency of the solvent molecules. The vapour pressure of the solution reduces as the concentration of the solute increases and so does that of the solvent. The number of solvent molecules on the surface is reduced hence fewer molecules leaving the liquid. Additionally, the intermolecular forces in the solution are usually high than for the pure substances. The molecular model of the lowering of vapour pressure is shown in Figure 1.8.

1.9.1 Boiling point elevation and freezing point depression

Both boiling point and freezing points are colligative properties. The addition of a non-volatile solute increases the boiling point of the liquid. For dilute solutions the boiling point is directly proportional to molal concentration of the solute.

$$\Delta T_b = K_b m \qquad (1.24)$$

where K_b is the molal boiling point constant with units of °Cm^{-1}. The molal concentration is a concentration on a mole per weight basis, 1 molal solution contains one mole solute per kg of solvent.

The freezing point on the other hand reduces due to the presence of a non-volatile solute. The freezing point refers to the temperature at which both liquid and solid simultaneously exist. A heterogeneous equilibrium exists between the pure solid solvent and the solution in which x_B mole fraction of solute is present. The freezing point is related to molal concentration of the solute in the expression

$$\Delta T_f = K_f m \qquad (1.25)$$

where K_f is the freezing point depression constant with the units °Cm^{-1}.

1.9.2 Osmosis

Osmosis is the flow of material through a semi-permeable membrane in which the pores allow passage of solvent molecules but are too small for solute molecules. This process is particularly important in living things where various mixtures and solutions are separated by membranes. Many plant and animal cell walls are made of semi-permeable membranes. Figure 1.9 illustrates this process. Consider a cell consisting of two compartments separated by semi-permeable membrane one of which contains a dilute solution and the other pure water. The liquid in both compartments is set such that they are at the same level. After some time the liquid in the left compartment rises whilst the level on the right hand side decreases.

The water molecules from the right migrate to the left whilst the solutes are retained in the same side. At some point the flow of the solvent ceases due to an opposing pressure known as osmotic pressure denoted by, π.

$$\pi = \frac{cRT}{M}$$

where c is the concentration in g L^{-1}, R is the gas constant, T is the absolute temperature and M is the molar mass.

Interactive Exercise: Colligative Properties

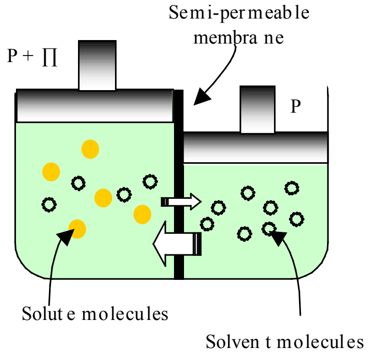


Figure 1.9 Diagram showing the migration of water molecules from the right hand side to the left. The large solute molecules remain on the left hand side.

Example 3

Albumin is human protein plasma with a molar mass of 69 000 g mol^{-1}. What would be the osmotic pressure of a solution of this protein containing 2.0 g per 100 mL at 25 °C. Assume that the experiment is carried out using a salt solution for solvent and a membrane soluble to the salt.

Solution

We have defined the osmotic pressure as the force that must be applied to just prevent osmotic flow and is given by the equation

$$\pi = \frac{cRT}{M}$$

We substitute the information given in the above equation

$$\pi = \frac{20\ \mathrm{g\ L^{-1}} \times 0.082\ \mathrm{L\ atm mol^{-1}} \times 298\ \mathrm{K}}{69\,000\ \mathrm{g\ mol^{-1}}}$$
$$= 7.08 \times 10^{-3}\ \mathrm{atm}$$

Practice problem 3

Insulin controls glucose metabolism. A solution of 2.0 g of insulin in 250.0 mL of water has an osmotic pressure of 26.1 torr at 30°C. What is the molecular weight of insulin?

(a) 7.5×10^3

(b) 5.8×10^3

(c) 3.4×10^3

(d) 4.2×10^3

(e) 6.8×10^3

Learning activity # 2

Title of Learning Activity: Colloids

On completion of this Unit, the learner should be able to:

- Describe the properties of colloidal systems
- Differentiate the different types of colloidal systems
- Explain factors affecting the stability of colloidal systems
- Describe and explain the properties of colloids such diffusion, osmosis, viscosity and electrical properties of colloidal systems

Summary of the learning activity

This learning activity is about colloids and their properties. By definition these are solutions with particles in a particular size range and exhibit characteristic properties. The colloidal system is a homogeneous system comprising a disperse phase in the range 50 -2000 Å in a continuous phase. Colloids are found in many natural and synthetic products and have their own peculiar properties. These properties are related primarily to the particle size and surface. In this activity, the learner is introduced to colloidal systems, the types of colloids and how such colloidal systems are prepared. Since colloidal systems are in part defined based on size it is important that the size of the disperse phase be maintained within the colloidal range. Hence, factors that affect colloidal stability are also examined. The unique properties of colloids, such as electrical and surface properties are discussed. Colloids are particularly significant to the study of surface phenomenon because their surface area-to-volume ratio is very large. Consequently, their properties are dominated by events at their surface.

List of REQUIRED readings

- Colloids
- Interfaces, Colloids And Gels

List of relevant useful links

Experiments On Surface Phenomena And Colloids

http://www.funscience.com

Colloids

http://ull.chemistry.uakron.edu/genobc/Chapter_07/

List of relevant MULTIMEDIA resources

- Computer with internet connectivity to enable access to open source learning materials and interactive learning through email, video conferencing and use of CD-ROMs
- QuickTime Movie Player Software
- Shockwave Player Software
- Macromedia Flash Player Software

Detailed description of the activity

The study of colloids starts by establishing the nature of colloids and the different types of colloidal systems that exists: lyophilic and lyophobic. The basic method used to produce colloidal systems is discussed followed by factors that affect their stability. You will also learn how such systems can be stabilised to maintain colloidal characteristics and properties. Properties associated with colloids such as Brownian motion, diffusion, osmotic pressure and viscosity will be studied. The effect of adsorption of charged species onto colloid particle surfaces is covered.

Formative evaluation

- As you make your way through this learning activity you will come across problems to test your conceptual understanding of the subject matter
- Rapid quizzes are provided to check your understanding
- Practical experiments will be given to evaluate your understanding of theory-practice relations
- Simulated experiments/exercise will given to test your understanding of certain concepts

Learning activities

Colloids are a class of materials found in a wide range of products from cosmetics, food, paints to pharmaceuticals. The substances include solids, emulsified liquids, clays, gels and proteins. The colloid system consists of small particles dispersed in a continuous phase. Although they are aggregates of atoms or molecules, colloidal particles are not ordinarily seen by an optical microscope. It should however be noted that the size limits are somewhat arbitrary and some systems may contain particles that are outside the size range. The extensive interface created between the particles and disperse phase is a predominant feature of colloidal systems. The surface area is so much larger than an equal volume of particles. For example, colloidal platinum is an effective catalyst, which is achieved by absorbing the reactants to its surface. The colour of a colloidal system is affected or related to the size of particles. Gold for example gives a red colour in a sol form but turns blue as the size increases.

Antimony and arsenic trisulfides exhibit colour changes associated with the particle size of the colloidal system too. The basic distinctions and definitions in this Unit are indicated below.

- A dispersion is a system in which a dispersed phase is distributed through a continuous phase.
- Dispersions may be molecular, colloidal or coarse. The classification of a particular dispersion into a particular sub-type is based on the particle size of the dispersed phase. Molecular dispersions are homogeneous, whilst colloidal and coarse dispersions are heterogeneous.
- A coarse dispersion may be either a suspension (in which the dispersed phase is a solid) or an emulsion (in which the dispersed phase is a liquid).
- The properties of dispersed systems depend on the 'bulk' surface properties of the components of the system.

2.1 Nature of a colloidal system

It is not easy to give a precise definition of colloidal systems. A definition that is frequently used is that it is system comprising of two phases one of which consists of minute particles (disperse phase) which are dispersed uniformly through out the second phase (continuous or dispersion phase). When one considers our every day encounters, one can identify many systems that fit into the description just given. Many paint and adhesive products have changed from hydrocarbon-solvent base to emulsions. The kitchen is also abound with emulsion systems – mayonnaise and cream are such examples. More specifically a colloidal system is defined on the basis of the system of particles of the dispersed phase. Having said that, a dispersion may be classified as molecular, colloidal or coarse depending on the size of particles as shown in the Table 1 below.

Table 1 Molecular size and type of dispersion system

Type	Size of particles dispersed	Types of system
Molecular dispersion	< 50 Å	homogeneous system
Colloidal dispersion	< 50-2000 Å	heterogeneous system
Coarse dispersion	> 2000 Å	heterogeneous system

A mixture of sand and water can be shaken to give a system in which sand particles are dispersed in water. To form a suspension, particles must be of a size greater that 1000 nm. Colloidal systems can be classified by the nature of the dispersed and the continuous phase.

Table 2 Classification and examples of common types of colloidal systems.

Types	Dispersed phase	Continuous phase	Examples
Aerosol	liquid	Gas	Insecticides sprays, deodorants etc
Foam	Gas	Liquid	Soap suds, whipped cream
Emulsion	Liquid	Liquid	Cream, mayonnaise, paints
Sol	Solid	Liquid	Starch in water
Solid sol	Solid	Solid	Alloys, pearls
Smoke	Solid	Gas	Dust, smog

Particles of a colloidal system, exhibit random motion similar to the erratic motion of molecules described when you covered kinetic molecular theory of gases. The erratic movement of colloidal particles is called the Brownian movement after the Scottish botanist Robert Brown.

2.2 Classification of colloids

Colloids can be conveniently classified as either lyophilic, lyophobic or association colloids based on the interaction of particles in the disperse phase and molecules of the dispersion medium.

2.2.1 Lyophilic colloids

Lyophilic colloids are colloids in which there is strong interaction between the colloidal particles and the dispersion medium. There is a strong attraction between the particles and the dispersion medium, which results in a thermodynamically stable system. Many of the properties of this class are due to the attraction between the particles and disperse phase leading to solvation (attachment of solvent molecules to molecules in the disperse phase). A hydrophilic colloid is one in which water is the dispersion medium. The attraction between the dispersed particle and water molecules leads to hydration of the particles, molecules or ions. Examples of lyophilic colloids include gelatin, acacia, insulin and albumin which produce lyophilic colloids in aqueous dispersion medium. Polystyrene and rubber can be dispersed in non-aqueous (organic solvent) medium.

2.2.3 Lyophobic colloids

The particles in lyophobic systems have a '*great dislike'* for the dispersion medium. There is little attraction between the particles in the disperse phase and the dispersion phase. Typically, lyophobic colloids are composed of inorganic substances disperse in an aqueous medium, water. Examples include silver, gold, silver iodide and arsenous sulphide. The methods used to prepare lyophobic colloids are inherently different to those used for lyophilic colloids. Two methods involve either dispersion of particles in the continuous phase or aggregating particles to a colloidal size.

(a) Dispersion methods

The dispersion method may involve the use of high sonic generators in excess or 20, 000 cycles per second or production of an electrical arc within a liquid. In the electric arc method, metal of the electrode is discharged as vapour into the continuous phase. A third method involves grinding and milling of the material to be dispersed using a colloidal mill. A colloidal mill essentially consists of high speed rotating disc, separated from a stationary disc by about 25 µm. Particle in a colloid can be reduced to 1 µm or less. Generally, a stabilizing agent has to be added to prevent agglomeration of the colloidal particles.

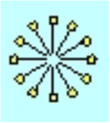
(b) Condensation method

The method involves creating particles of colloidal size from a molecular dispersion. Very concentrated or very dilute solutions are used with carefully controlled conditions to prevent growth of large particles. An alternate to the precipitation method, colloidal ferric hydroxide, can be formed by boiling a solution of ferric chloride to produce ferric hydroxide. Molecules of the freshly prepared hydroxide then agglomerate to form particles of a colloidal size.

$$3FeCl_3 \leftrightarrows 2Fe(OH)_3 + 6HCl$$

The colloid is stabilized by the particles absorbing Fe^{3+} ion from solution.

2.2.4 Association colloids



Soap molecules can cluster together to form aggregates called micelles. These molecules have both a polar and hydrophobic component. Such molecules are known as surface active, surfactants or amphiphiles. The amphiphiles may be predominantly hydrophilic (water loving) or hydrophobic (water hating).

Micelle Formation

Surface-active materials exhibit unusual properties. In dilute solutions highly surface active substances act as normal solutes. At a fairly well defined concentration their physical properties (e.g. osmotic pressure, turbidity, electrical conductance and surface tension) change abruptly. The abrupt change in physical properties are explained via the formation of aggregates known as *micelles*. Micelles are colloid-sized clusters of molecules in which the hydrophobic tails congregate in the interior the hydrophilic component reside on the outerside towards the water as shown in the adjacent diagram. The concentration at which the formation of micelles becomes appreciable is known as critical ***micelle concentration (cmc).*** The micelles that form are in the size of colloial particles hence the term *association colloids*.

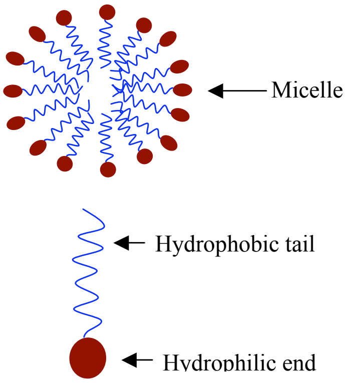


Figure 2.1 Diagram illustrating the structure of micelles

2.3 What factors promote formation of micelles?

- The intermolecular attraction between the hydrocarbon chains in the interior represents an energetically more favourable condition
- Micelles permit strong water-water (H-bonding) which would otherwise be prevented if in solution as a single molecule.

Some factors work against the formation of micelle structures

- Increasing the hydrophobic part of the surfactant molecules in an aqueous medium, cmc of ionic surfactant is approximately halved by addition of each 'CH_2' group. For non-ionic the decrease is by a factor of 10 for each 'CH_2'.
- Lowering of temperature. Micellisation is endothermic and is entropy driven ($\Delta H = \Delta G + T\Delta S$).
- Addition of simple salts. Repulsion between charged groups is reduced.

2.4 Stability of colloids

The stability of a colloid is important in many industries such as food and beverages, pharmaceuticals, paints and pigments. The question of stability when applied to colloids is whether the systems can resist flocculation or aggregation after a considerable period of time. Stability will generally depend on a balance of attractive and repulsive forces between particles when they approach each other. Mutual repulsion of particles leads to a stable dispersion where as if the particles have little or no repulsive forces the colloidal system eventually breaks down i.e. flocculation, aggregation and coagulation of particles takes place.

The mechanism involved in breaking down of a colloidal dispersion involve initially particle adhering to each other forming aggregates (floc) that grow with successive additions. Continued aggregation of particles eventually leads to coagulation. Separation of the medium occurs by two modes depending on the differences in density between disperse and dispersion medium. When the aggregates are denser the dispersion medium the system separates by sedimentation whilst creaming occurs when the dispersion medium is less dense. Very often, the terms flocculation and coagulation are used interchangeably. However, there is some difference in the two; coagulation is not reversible while flocculation (deflocculation) is.

The stability of a colloidal system is essentially related to colloid particle size remaining unchanged over time. The break down of a colloidal system essentially involves processes that lead to the formation of larger particles. The diagram below helps illustrate the basic concept.

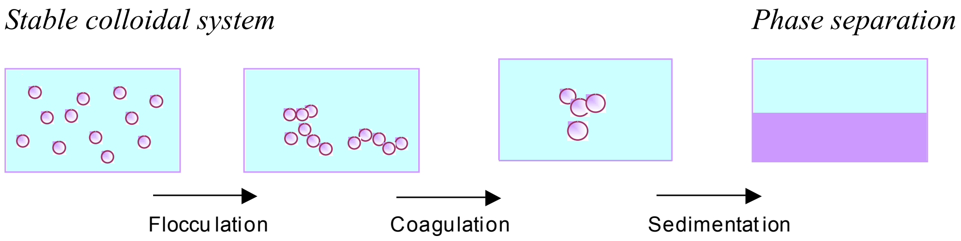


Figure 2.2 Illustration of the process leading to the break down of a colloidal system.

2.5 Colloid Properties

Colloids exhibit several properties, which are primarily linked to the large surface area of the dispersed particles. These properties may be broadly classified into kinetic and electrical properties. The former include Brownian motion, diffusion, osmosis and viscosity.

(a) Brownian motion. Colloid particles exhibit erratic random motion. The motion has been ascribed to the bombardment of the particles by molecules in the dispersion medium. The motion is affected by size and also the viscosity of the medium. Smaller particles have higher random motion whilst high viscosity reduces Brownian motion.

(b) Diffusion. Diffusion is the spontaneous movement of particles from a region of high concentration to one of a lower one. The process is a consequence of the Brownian motion and proceeds until such a point where the concentration of the system becomes uniform. The diffusion process maybe explained using Fick's first law

$$dC = DS \frac{dc}{dx} dt \qquad (2.1)$$

where *dC* is the amount of substance diffusing in time *dt* across a plane area of surface area *S*, *dc* is the change of concentration with distance travelled *dx*. The diffusion coefficient, *D*, represents the amount of substance diffused per unit time across an area.

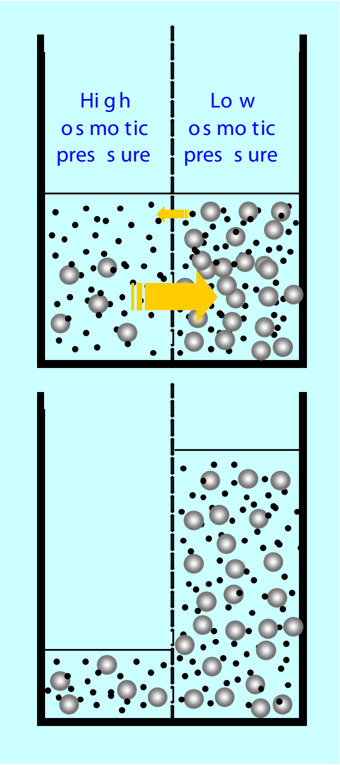


Figure 2.3 Diagram illustrating the osmotic process

(c) **Osmotic pressure.** Osmosis is the movement of solvent molecules (water) through a semi-permeable (permeable only to solvent molecules) membrane from an area of low solute concentration to one of higher solute concentration. The pressure exerted by the flow of water through a semi-permeable membrane separating two solutions with different concentrations of solute is known as the osmotic pressure. A useful equation that relates the concentration and osmotic pressure is the van't Hoff equation

$$\pi = cRT \qquad (2.3)$$

The equation is particularly useful in determining the molecular weight of a colloid though the equation

$$\pi = m/M\ RT \qquad (2.4)$$

where m is the mass in grams of solute per litre of solution and M is the molecular weight. The equation can be re-arranged to give

$$\pi/m = RT/M \qquad (2.5)$$

The quantity π/m is often a linear function of the form $\frac{\pi}{m} = RT\left(\frac{1}{m} + Bm\right)$ where *B* is a constant dependant on particular solvent-solute system and is applicable to systems with low concentration of solutes.

(d) **Viscosity.** The measure of the resistance of flow of a fluid system is known as viscosity. Viscometry studies can provide information relating to the shape and molar mass of particles in solution. For dilute colloidal dispersions the viscosity is given by

$$\eta = \eta_0(1 + 2.5\phi) \qquad (2.6)$$

where η_0 is the viscosity of the dispersion medium and η is the intrinsic viscosity of the dispersion medium with a volume fraction of colloidal particles ϕ. The volume fraction is the volume of the colloidal particles divided by the total volume of the dispersion. It is equivalent to the concentration term. The viscosity is measured commonly using a capillary viscometer. The relative viscosity which is the ratio η/η_0 is given by the expression

$$\eta_{rel} = \frac{\eta}{\eta_0} = 1 + 2.5\phi \qquad (2.7)$$

whilst the specific viscosity is related to the specific viscosity through the equation

$$\eta_{sp} = \frac{\eta}{\eta_0} - 1 = \frac{\eta - \eta_0}{\eta_0} = 2.5\phi \qquad (2.8)$$

It follows from the above equation that the ratio of the specific viscosity to ϕ is a constant i.e.

$$\frac{\eta_{sp}}{\phi} = 2.5 \qquad (2.9)$$

Since the volume fraction is related to concentration

$$\frac{\eta_{sp}}{c} = k \qquad (2.10)$$

where c is the concentration and k is a constant. The equation is commonly expressed as a power series

$$\frac{\eta_{sp}}{c} = k_1 + k_2 c + k_3 c^2 \qquad (2.11)$$

The value of $\frac{\varsigma_{sp}}{c}$ can be determined by extrapolating to infinite dilution a plot of $\frac{\varsigma_{sp}}{c}$ against c.

Approximate molar masses are easily determined using the Mark-Houwink equation

$$[\eta] = KM^{a} \qquad (2.12)$$

The constants K and a are characteristic of a particular polymer-solvent system.

(e) Electrical particles. Colloidal particles are affected by charges adsorbed on the surface of the particles. Charges are adsorbed when particles are dispersed in a liquid medium, an electric double layer forms around the particle as shown in the Figure 2.4 below. Such a system can be attained by adding a salt, for example potassium iodide, to a dilute solution. The stability of a colloidal system is affected by the presence and magnitude of a charge on a particle. The presence of a charge on particle creates a shield that prevents coalescence of the particles via mutual repulsion. Lyophobic sols are thermodynamically unstable, the presence of electrical charges impart stability due to repulsions that prevent coagulation.

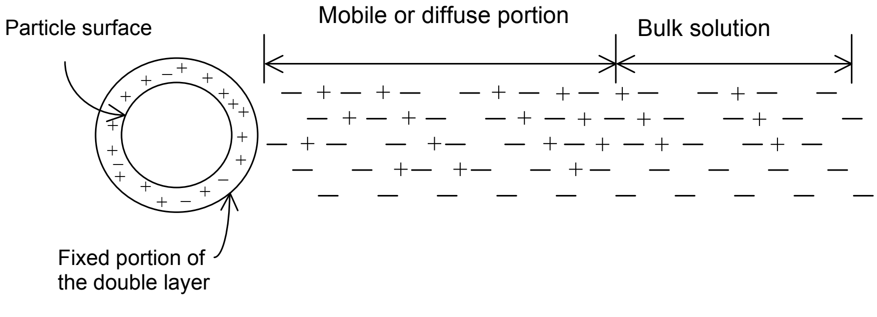


Figure 2.4 Illustration of double layer formation in the vicinity of a colloidal particle. Diagram shows the position of the particle, diffuse portion and the bulk solution.

Learning activity # 3

Title of Learning Activity: Equilibrium of Phase

On completion of this Unit, the learner should be able to:

- Explain concepts of vaporization, boiling, vapour pressure, and how these are affected by variables of temperature and pressure and interpret phase diagrams
- Be able to calculate all relevant quantities in binary equilibrium phase diagrams: number of phases, composition of phases, phase amounts.
- Be able to interpret the Gibb's phase rule.
- Describe the role of Gibbs energy in determining pure species phase equilibrium.

Summary of the learning activity

In this unit the learner is introduced to the concept of equilibrium of phases. A phase is described as a sample of matter with definite composition and properties that are characteristic of that phase and different from the others. The states of matter: solid, liquid and gas exist in different phases. The learner will study the transformation of the various states of matter as a function of temperature and pressure through phase diagrams. Phase diagrams basically map-out the transformation of a substance from one phase to another. Gibb's phase rule is introduced and used to identify the number of variables that can be changed independently while remaining in the same phase. At the end of the unit the learner will be able to explain, draw and interpret phase diagrams identifying significant points.

List of REQUIRED readings

- Phase Diagrams
- Phase Equilibrium And Intermolecular Interactions

List of relevant useful links

General Chemistry

http://www.vias.org/genchem/wrapnt_phase_equilibrium_and_intermolecular_interactions74.html

Phases Changes

http://www.chm.davidson.edu/ChemistryApplets/index.html

List of relevant MULTIMEDIA resources

- Computer with internet connectivity to enable access to open source learning materials and interactive learning through email, video conferencing and use of CD-ROMs
- QuickTime Movie Player Software
- Shockwave Player Software
- Macromedia Flash Player Software

Detailed description of the activity

The learner will in this activity study the concept of phases and their transformation. The Unit starts by explaining what a phase is, that it has a definite composition and its properties are distinct from other phases. The learner will examine the transition taking place between the condensed and gas phases using phase diagrams. Gibb's phase rule is introduced and used to determine the number of variables that can be changed independently while remaining in the same phase. The learner will also be able to draw and interpret phase diagrams.

Formative evaluation

- As you make your way through this learning activity you will come across problems to test your conceptual understanding of the subject matter
- Rapid quizzes are provided to check your understanding
- Practical experiments will be given to evaluate your understanding of theory-practice relations
- Simulated experiments/exercise will be given to test your understanding of certain concepts

Learning activities

3.1 What is a phase?

The term phase is often used synonymously with states of matter, the latter being gas, liquid and solid. A phase on the other hand is a sample of matter with definite composition and uniform properties that distinguishes it from other phases with which it is in contact. One can then talk of states of matter in different phases i.e. gas, liquid and solids phases of a substance. A change in phase occurs when a substance is converted from one phase to another at a characteristic temperature for a given a pressure. By definition the transition temperature is the temperature at which the chemical potentials in the phases are equal. For example, in the transition of ice to water, the chemical potentials μ (solid) = μ (liquid).

Phase diagrams

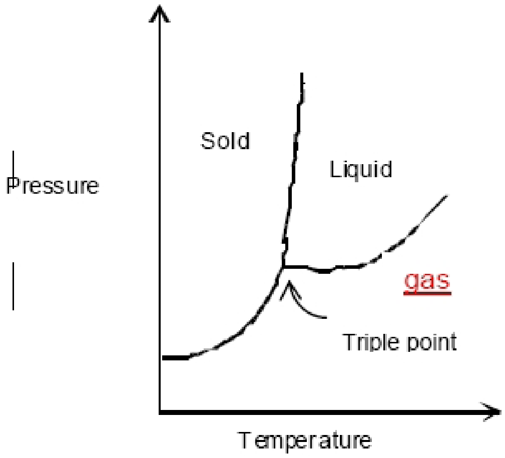


Figure 3.1 Phase diagram depicting the changes in phase for a hypothetical substance

Phase diagrams are a means to represent regions of temperature and pressure at which different phases are thermodynamically stable. The phases present in the system at different T and P, can be conveniently represented using pressure-temperature plot. The boundary between the regions, show positions were temperature (T) and pressure (P) of the two phases are at coexistence in equilibrium. Consider for example, the hypothetical system, shown in the Figure 3.1.

Three regions can be identified where the solid, liquid and gas are stable. The diagram shows that the solid phase is stable at low temperature and high pressure whilst the gas phase is stable at high temperature and low pressure. The regions are separated by a boundary referred to as a phase boundary. Take for example, the pressure of a vapour in equilibrium with its condensed phase, is known as the vapour pressure of the substance, at the specified temperature. The vapour pressure of the substance as indicated in the diagram increase with increasing temperature since the escaping tendency of molecules gets higher.

Triple point

The triple point of system is the temperature and pressure at which all phases coexist – gas, liquid and solid. It represents the point where the vapour, liquid and solids phases are in equilibrium. It is characteristic of a substance and as such occurs at a definite temperature and pressure. The triple point indicates the lowest pressure and temperature at which a liquid substance can exist.

3.2 Constructing phase diagrams

Phases diagrams allow us examine the changes that mixtures undergo when subjected to heat or when cooled. The diagrams enable us to determine if two or more substances are mutually miscible under a given set of conditions. The significance of phase diagrams is found in a whole range of fields from semi-conductors to petroleum refining. It is therefore important to develop skills to draw phase diagrams. Gibbs' Phase rule assists us in this regard.

3.3 Gibbs' phase rule

The phase rule is essentially used to determine the degrees of freedom, or number of variables that can be changed independently while still remaining in the same phase. Josiah Willard Gibbs (1876) deduced from thermodynamics a relationship between the possible number of degrees of freedom in a closed system at equilibrium, in terms of the number of separate phases and the number of chemical components in the system. For a system at equilibrium, the relationship P + F = C + 2 holds.

The **number of phases** is denoted by P. A phase is a physically separable part of a system with distinct physical and chemical properties. Each phase consists of one or more ***components*** (C), chemically independent constituents of a system. A ***constituent*** being a chemical species that is present (ion or molecule) in the system. The general phase rule is usually stated in the form F = C – P + 2. The example below helps illustrate the concept. Consider the three points A, B and C indicated on the diagram for a pure substance.

Point A

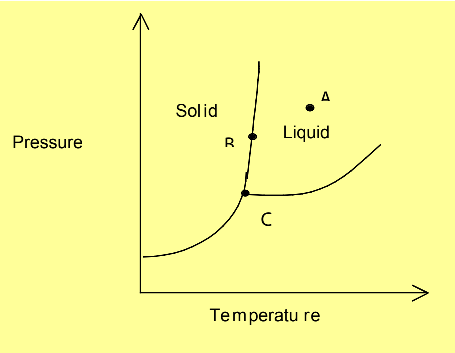


Figure 3.2 Phase diagram showing significant points involved in phase transformation

The first point A, lies in the liquid phase region. The temperature or pressure can be changed independently while still remaining in the liquid phase i.e. both temperature and pressure could change by a small amount without affecting the number of phases. The number of components, C = 1 and since there is only one phase P = 1 therefore the number of degrees of freedom F = 1– 1 + 2 = 2.

Point B

Since the point lies at the phase boundary, F = 1– 2 + 2 = 1. There is only one degree of freedom indicating that only one variable can be changed independently at any one time. One variable is forced to change in order to remain within the phase boundary. A typical example would be along the boiling or melting point boundaries.

Point C

The point C, represents the triple point, all three phases are in existence at this point i.e. P = 3. The number of degrees of freedom F = 1 – 3 + 2 = 0. No variable can be changed at this point without causing a change in the number of phases. Any change in temperature or pressure will result in change in the number of phases.

1.3 Phase diagram for a two component system

Phase diagrams comprising more than two components are frequently encountered in chemistry. Under such circumstances, concentration becomes an important factor for consideration. The simplest example of such a system is a two-component (or binary system) for liquids that can break into two. Consider a system with two components A and B which can form pure crystals of A and B respectively. We can plot a diagram of temperature or pressure against the composition. If pressure is kept constant then only two variables remain, temperature and composition. The temperature composition curve for a benzene-naphthalene binary system is shown in Figure 3.3.

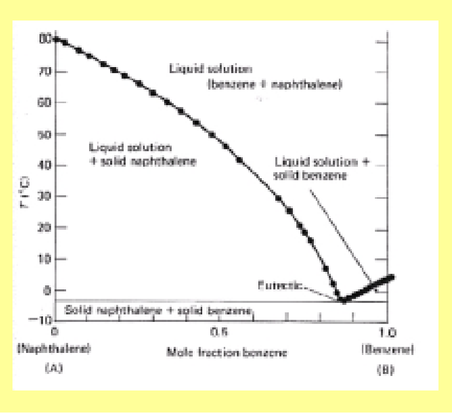


Figure 3.3 Temperature composition curve for benzene-naphthalene binary system

The component shown on the left hand side is by convention A (in this case naphthalene) while the component on the right is designated as B (in this case benzene). The plot shows two intersections, on the left the curve intersects with the ordinate axis at the point of pure A whist on the right the intersection occurs at the point of pure B. The lowest point in the curve is known the *eutectic* – the lowest possible temperature of solidification for any mixture of specified constituents. Numerous binary systems in which the liquids are completely miscible and the solids insoluble in each other have phase diagrams similar to the one shown in Figure 3.3.

Learning activity # 4

Title of Learning Activity: Electrochemistry

Summary of the learning activity

On completion of this Unit, the learner should be able to:

- Explain and describe an electrochemical cell
- Write cell diagrams for voltaic cells diagrammatically and in short notation
- Use the concept of reduction potentials to explain reactions taking place at the anode and cathode
- Explain and use reduction potential to predict spontaneity of chemical reactions
- Relate emf to Gibbs free energy and carry out related calculations

This Unit on electrochemistry deals with the study of the movement of charge between matter. It is important in many industrial as well life sustaining processes. Many of these reactions are studied at interfaces and essentially involve transfer and gain of electrons by various species i.e. redox reactions that the learner would have come across previously. We begin by focusing on the processes taking place at atomic level when a metal is in contact with a liquid such as water. It is observed that there is movement of ions from the metal into solution creating a double layer. However, such potential difference is not easily measurable directly. To circumvent this difficulty, the concept of the standard hydrogen electrode is introduced in which electrode potentials are measured against a set standard (the standard hydrogen electrode). The standard electrode potential gives an idea of the relative tendency of chemical species to gain electrons and be reduced. Two cells can be coupled to create an electrochemical cell, which is known as a galvanic (or voltaic) cell. The galvanic cell produces electricity due to spontaneous reactions taking place in the half-cells. A link is made between the Gibb's free energy, the cell potential, and the equilibrium constant. This not only enables prediction of whether the coupled cells reactions are spontaneous but also the determination of the equilibrium constant.

List of REQUIRED readings

- Electrochemistry (Stephen K. Lower)
- Electrochemistry (James C. Baird)

List of relevant useful links

Electrochemistry

http://www.chem.queensu.ca/people/faculty/mombourquette/firstyrchem/electro/index.htm

STEVE MARSDEN'S CHEMISTRY RESOURCES ELECTROCHEMISTRY

http://www.chemtopics.com/unit13/unit13f.htm#lecture

Chemistry Experiment Simulations and Conceptual Computer Animations

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/simDownload/index4.html

List of relevant MULTIMEDIA resources

- Computer with internet connectivity to enable access to open source learning materials and interactive learning through email, video conferencing and use of CD-ROMs
- QuickTime Movie Player Software
- Shockwave Player Software
- Macromedia Flash Player Software

Detailed description of the activity

The learner will be introduced to the phenomenon of the charge transfer at interfaces and the formation of potential difference. This knowledge will then be used to explore the concept of standard electrode potentials that are measured against the hydrogen electrode. The relative tendency to gain electrons for the chemical species provide a basis for predicting the spontaneity of coupled electrochemical cells. The linkage between the maximum work done in a voltaic cell and ΔG is made. This also enables association of the cell potential to the equilibrium constant i.e. the Nerst equation.

Formative evaluation

- As you make your way through this learning activity you will come across problems to test your conceptual understanding of the subject matter
- Rapid quizzes are provided to check your understanding
- Practical experiments will be given to evaluate your understanding of theory-practice relations
- Simulated experiments/exercise will be given to test your understanding of certain concepts

Learning activities

Electrochemistry is the study of the movement and separation of charge in matter. Electrochemistry is behind the batteries that power many of our electronic appliances, semiconductors and photovoltaic applications, medical sensors and gives a better understanding of many biochemical processes. The science unites electricity and chemistry. This learning activity examines how electricity can be generated from chemical reactions and electricity to cause chemical reactions. Since electricity involves movement of charge (electrons), the study of electrochemistry gives additional insight of oxidation-reduction reactions.

The conversion of chemistry into electricity usually takes place at the interface with electrodes, usually a metal in contact with a solution of salt or other suitable compounds soluble in water. We therefore start our study of electrochemistry by examining what happens at the interface of a metal and a solution.

Electrochemical cells

4.1 What happens when a metal such as zinc is dipped in a solution containing zinc ions?

Consider a piece of zinc metal that is immersed in water. The zinc atoms at the surface of the metal are attracted into solution leaving their electrons behind. The increase in the number of electrons left behind lead to a build-up of the negative charge.

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

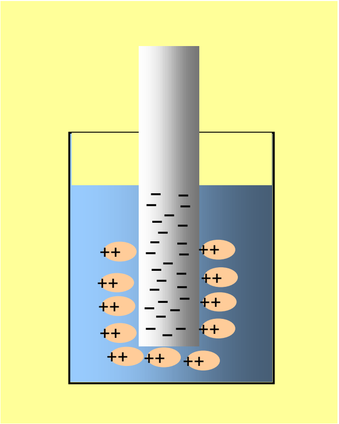


Figure 4.1 Illustration of double layer formation in the vicinity of a metal electrode

The build of positive charge occurs near the metal due the presence of Zn^{2+} ions. As the process proceeds, it becomes increasingly difficult for zinc ions to leave due the build-up of the negative charge. The process eventually comes to a halt with some kind of equilibrium established. An electrical double layer is established in which an inner monolayer of adsorbed ions and an outer layer that compensates the local charge. The study of electrochemistry generally involves the study of processes occurring at a metal and a conducting solution (electrolyte) i.e. with the double layer.

Although there is potential difference established between the electrode and the solution, its measurement is not easy. Measuring potential difference would require bringing a second metal electrode effectively setting a new equilibrium (another electrode). It is for this reason that single electrode potentials are not directly measurable. A way around this difficult is to measure the potential difference between two double layers. Hence, an agreed electrode was chosen against which all other electrodes are measured against. The system that was selected as a reference is the standard hydrogen electrode.

Click Simulation!: Zinc Copper Transfer Simulation

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/simDownload/index4.html

4.2 The standard hydrogen electrode

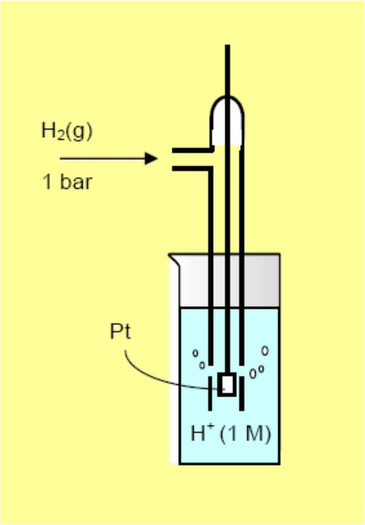


Figure 4.2 The standard hydrogen electrode half-cell

In the standard hydrogen electrode, hydrogen gas is bubbled over platinum metal immersed in an aqueous solution containing hydronium ion. Platinum is ideally chosen since it is inert. Its purpose is to establish an electric contact with the solution. The solution has concentration of 1 M of hydronium ions, the gas pressure of hydrogen is maintained at 1 bar and temperature fixed at 25 °C. As the hydrogen flows over the porous platinum equilibrium is set-up between the hydrogen molecules and the hydrogen ions in solution.

$$2\ H^{+}(aq) + 2e^{-} \rightleftharpoons H_2(g)$$

The potential for the cell is taken as standard and measurements are made against this equilibrium (electrode). An electrode potential of zero volt (E°) assigned to it.

Having established our standard, we now connect another electrode and measure the voltage between the two cells.

4.3 Standard reduction potentials

The standard reduction potential is the tendency of chemical species to gain electrons thereby getting reduced. Each species tends to have an intrinsic tendency to acquire electron. The more electropositive the reduction potential is, the greater the tendency to acquire electrons. All reduction potentials are defined relative to the SHE.

A system in which two electrodes are in contact with a conducting solution is known as electrochemical cell. Consider the example of the zinc electrode which is coupled with the standard hydrogen electrode.

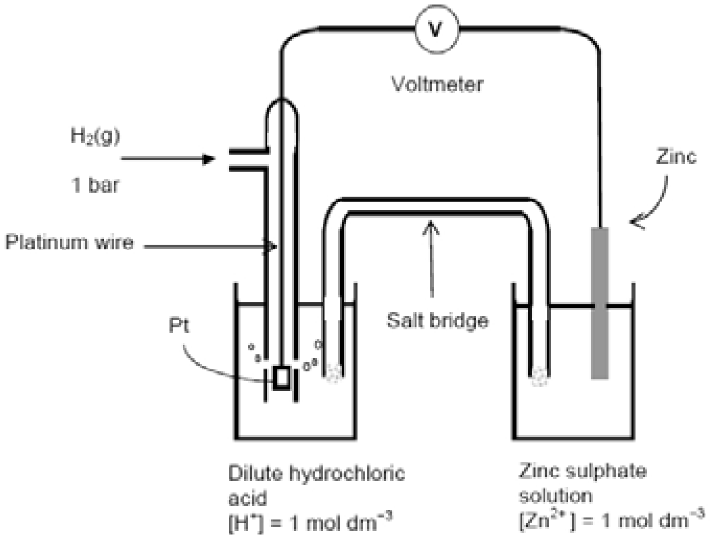


Figure 4.3 Diagram of a schematic diagram of the zinc and standard hydrogen electrode electrochemical cell.

Simulation Click!: Standard Hydrogen Electrode

Example 1

Arrange the following in their decreasing order of ability to oxidise:

Fe^{3+}, F_2, Pb^{2+} and Sn^{4+}.

Solution

The species with the greatest tendency to gain electrons itself being reduced will be the one with the more positive standard reduction potential. The standard potential can be obtained from Table of standard electrode potentials as shown below.

$Fe^{3+} (aq) + e^- \leftrightharpoons Fe^{2+} (aq)$ $E° = + 0.77 V$

$F_2(g) + 2e^- \leftrightharpoons 2F^- (g)$ $E° = +2.87 V$

$Pb^{2+} (s) + 2e^- \leftrightharpoons Pb(s)$ $E° = – 0.13 V$

$Sn^{4+} (aq) + 2e^- \leftrightharpoons Sn^{2+} (aq)$ $E° = + 0.15 V$

The species arranged as follows according to the decreasing ability as oxidizing agents:

$F_2 > Fe^{3+} > Sn^{4+} > Pb^{2+}$

Practice problem 1

Given the following half reactions, assuming standard conditions, will have the greatest tendency to reduce.

$Mg^{2+} (aq) + 2e^-$ D Mg (s) $E° = – 2.35 V$

$Al^{3+} (aq) + 3e^-$ D Al (s) $E° = – 1.68 V$

$Cu^{2+} (aq) + 2e^-$ D Cu (s) $E° = – 0.34V$

(a) Al^{3+}

(b) Mg^{2+}

(c) Mg

(d) Cu^{2+}

4.4 Measuring the standard electrode potential of a metal

Each of the beakers in the diagram (Figure 4.3) are described as half-cells and the whole assembly as an electrochemical cell. The external circuit is created by a conducting wire linking the two half-cells. A salt bridge is included to complete the circuit. It comprises a potassium nitrate solution and avoids the introduction of another metal object into the system. The equilibria at the two electrodes are:

$Zn^{2+}(aq) + 2e^{-} \rightleftharpoons Zn(s)$

$2H^{+}(aq) + 2e^{-} \rightleftharpoons H_2(g)$

The reactions occurring at each electrode are known as half reactions. The metal has a greater tendency to lose electrons and form ions than hydrogen. Consequently there will be a greater build-up of electrons at the zinc metal. The difference of the charge between the two electrodes – potential difference – can be measured using a voltmeter as shown in the diagram (Figure 4.3).

The difference in the electromotive force between two Half-cells (E°) is given by

$$E^{\circ}_{cell} = E^{\circ}_{{}^{\circ}Zn^{2+}/Zn} - E^{\circ}_{{}^{\circ}H^{+}/H_2}$$

$$E^{\circ}_{cell} = E^{\circ}_{{}^{\circ}Zn^{2+}/Zn}$$

since $E^{\circ}_{{}^{\circ}H^{+}/H_2} = 0$ V.

The standard reduction potentials of many chemical species have been determined and can be found in datatables. By comparing the reduction potentials of chemical species we can predict what type of reactions are likely to occur within an electrochemical cell (or particular system). Tables of reduction potential are to be found in many sources.

4.4.1 Zinc electrode coupled with a copper electrode?

The standard hydrogen electrode can be replaced with copper electrode and the potential difference measured between the two. Such an arrangement is called a galvanic cell and enables investigation of reactions taking place at the two elecctrodes. Galvanic (or voltaic) cells produce electricity as a result of spontaneous chemical reactions at the electrodes. Consider our galvanic cell involving zinc and copper electrodes.

The zinc atoms lose electrons and go into solution leaving behind electrons. Since there is an external circuit, the electrons that remain go through the external wire via the measuring device to the copper electrode where they are discharged at the copper electrode.

The half reactions that take place at the two electrodes are

$Zn\ (s) \rightarrow Zn^{2+}(aq) + 2e^-$ oxidation

$Cu^{2+}(aq) + 2e^- \rightarrow Cu\ (s)$ Reduction

The net reaction in the electrochemical cell in Figure 4.4 is

$Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}(aq) + Cu\ (s)$

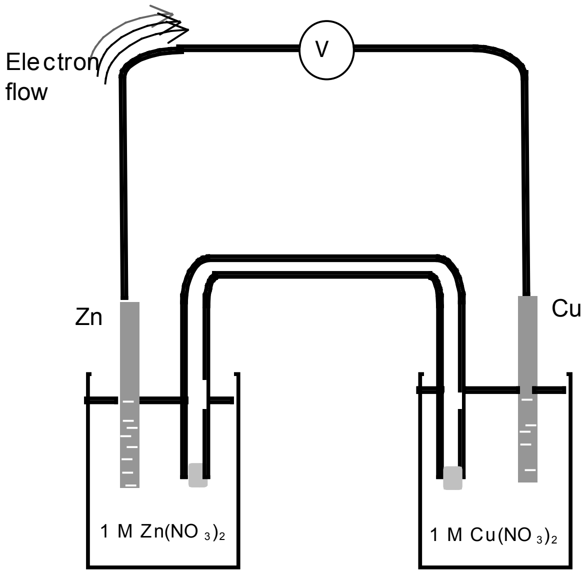


Figure 4.4 Schematic representation of an electrochemical cell for zinc and copper electrodes.

Electrochemical reactions involve loss of electrons (oxidation) and gain of electrons (reduction). The electrode at which oxidation occurs is placed on the left-handside whilst that where reduction occurs is placed on the right.

Simulation Click!: Zinc Copper Electrochemical Cell

4.4.2 Quick Cell Notation

A simpler way represeanting a cell is often used to the full diagram which can be long and tedious. The cell diagram depicted in Figure 4.4 can written as

Oxidation Reduction

$Zn(s)|Zn^{2+}(aq)||Cu^{2+}(aq)|Cu(s)$

↗ ↖

The vertical line shows
the phase boundary

The double line
represents the salt bridge

The electrode at which oxidation takes place is by convention the anode while reduction occurs at the cathode. The cell potential for the cell represented above can be calculated by taking the difference in potential between the two half-cells (or reactions).

$$E^{\circ}_{cell} = E^{\circ}_{Reduction} - E^{\circ}_{Oxidation}$$

$$E^{\circ}_{cell} = E^{\circ}_{Cathode} - E^{\circ}_{Anode}$$

Example 2

Calculate the cell potential for the electrochemical cell depicted in Figure 4.4

The reduction potentials for the two half-cells are as given below.

$Zn^{2+}(aq) + 2e^{-} \rightarrow Zn\ (s)$ $E^{\circ} = -0.76\ V$

$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu\ (s)$ $E^{\circ} = +\ 0.34\ V$

The E° for the cell is given by, $E^{\circ}_{cell} = E^{\circ}_{Reduction} - E^{\circ}_{Oxidation}$ we can substitute the relevant reduction potentials to get the value of the cell potential.

$$E^{\circ}_{cell} = 0.34 - (-0.76)$$
$$= 1.100\ V$$

Practice problem 2

Suppose that the Zinc half-cell was replaced with cadmium. The voltage for the new electrochemical cell can be measured and found as shown below.

$Cd(s)|Cd^{2+}(1\ M)||Cu^{2+}\ (1\ M)|Cu(s)$

What is the standard reduction potential for the $Cd^{2+}|Cd$ electrode?

(a) +0.34 (b) – 0.40 (c) 1.08 (d) + 0.40

Our calculations from the previous example has given a positive value for the cell potential based on the reaction equations as written. The reaction is spontaneous as written if the calculated cell potential is positive. If the caluculated value is negative – the reaction is nonspontaneous (but spontaneous in the opposite direction).

Batteries involving vegetables such as a potato, lemon or onion can be set-up to illustrate voltiaic properties. Batteries made of different electrodes, shapes or surface area might have different resistance. Electricity from vegtables?

4.5 Free energy and cell potential

In a voltaic cell work is done when a cell reaction takes place. The total work done is related to the electromotive force (emf) of the cell E°_{cell}, the number of moles of electrons transferred between the electrodes (n) and the electrical charge per mole of electrons which is Faraday's constant (F = 96 485 C/mol e^-). The total work therefore can be calculated from

$$W_{electrical} = n \times F \times E^{\circ}_{cell} \qquad (4.1)$$

The maxium available amount of work for a reaction is related to $-\Delta G$. We can thus combine the two equations to give us a linkage between cell potential and free energy as

$$\Delta G = -n \times F \times E^{\circ}_{cell} \qquad (4.2)$$

4.6 E_{cell} as a function of concentration – The Nerst Eqaution

The relationship between cell potential and concentration, is easiy established through Gibbs free energy. We have seen previuosly that

$$\Delta G = \Delta G° + RT \ln Q \qquad (4.3)$$

For ΔG and ΔG° we can make corresponding substitutions of $-\ nFE_{cell}$ and $-\ nF$ E°_{cell} to obtain

$$-\ nFE_{cell} = -\ nF E^{\circ}_{cell} + RT \ln Q \qquad (4.4)$$

which can be re-written as

$$E_{cell} = E^{\circ}_{cell} - \frac{RT}{nF} \ln Q \qquad (4.5)$$

The Nernst equation $$E_{cell} = E^{\circ}_{cell} - \frac{0.0592}{n} \log Q \qquad (4.6)$$

Example 3

If Fe^{2+} spontaneously oxidized by the oxygen of the air in acidic solution? Calculate ΔG and K.

Solution

Two reactions are involved with the corresponding potentials are

Oxidation: $2Fe\ (s) \rightarrow 2\ Fe^{2+}(aq) + 4e^-$ $E° = -\ 0.77\ V$

Reduction: $O_2(g) + 4H^+ + 4e^- \rightarrow H_2O\ (l)$ $E° = +\ 1.23\ V$

Overall cell potential

$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$ $E°_{cell} = 0.46\ V$

Note that the overall cell potential is positive signifying that the process is spontaneous.

The free energy is calculated from the equation $\Delta G = -nFE^\circ_{cell}$. Making the substitution $E^\circ_{cell} = 0.46$ V and n = 4 we obtain

$$\Delta G^\circ = -\,4\ \text{mol} \times 96485\ \text{C/mol} \times 0.46\ \text{V}$$

$$= -\,1.8\times10^5\ \text{J}$$

$$= -180\ \text{kJ}$$

The equilibrium constant is calculated from the relationship $\Delta G^\circ = -\,nRT\ \ln K$

$$\ln K = \frac{-\Delta G}{RT} = \frac{-(-180\,\text{kJ mol}^{-1})}{8.314\,\text{J mol}^{-1}\text{K}^{-1}\ \text{x}\,298\,\text{K}}$$

$$K = e^{72.7} = 3.7\times10^{31}$$

Note

Corrosion is an important chemical process commonly associated with metals. Some metals e.g. aluminium, form corrosion products that adhere to the metal and protect the metal to subsequent corrosion reactions. Iron oxide (rust) on the other hand fall constantly exposing new surfaces for corrosion. The metal continuously corrodes. The corrosion or rusting process is a typical redox reaction.

Practice problem 3

When ionic substances are placed in water, equilibrium is set up between its ions in solution and the excess solid phase. This equilibrium is measured by the solubility constant K_{sp}. Determine the solubility constant for silver chloride at 25 °C, given the following information.

$AgCl \leftrightharpoons Ag^+ + Cl^-$

Half-reactions:

$Ag^+ + e^- \rightarrow Ag(s)$	$E^\circ = +0.80$ V
$AgCl + e^- \rightarrow Ag(s) + Cl^-$	$E^\circ = 0.22$ V

Solution

(a) 6.3×10^{-9} (b) 1.69×10^{-10} (c)) 0.00 (d) $2.46 \times {}^{-20}$

Picture the process – production of copper

Ore being loaded on a 3000 tonnes truck for transportation to a crusher

Trucks transporting the ore in an open-pit mine (Nchanga open, Zambia)

Electrolysis

The opposite process takes place in an electrolytic cell to that in a voltaic cell. The electrolytic cell, another type of electrochemical cell, that makes use of electricity to cause non-spontaneous reaction to take place. Electrolysis is an immensely important process that allows the production of a wide range of industrial products.

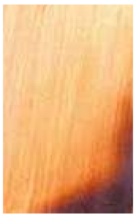
- The extraction of metals, notably aluminium, magnesium, and sodium.
- The preparation of halogens, for example chlorine.
- The refining of metals, such as copper and zinc.
- Electroplating

Copper is mined in a number of African countries, one of the most notable being Zambia.

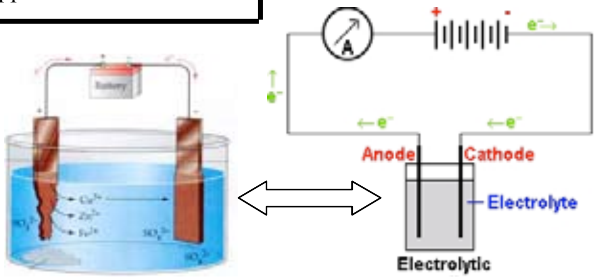
Copper on a conveyor en-route for processing

Smelter - High grade anodes being produced at Nkana smelter, Copperbelt, Zambia. The process produces sulphur dioxide which is converted into sulphuric acid for use in the leaching process of the copper oxide.

Electrowining cells - copper plate from the smelter are then dissolved in sulfuric acid and sent to the electrowinning cells for plating onto cathodes.



Copper cathode sheet ready for fabrication



Principle of copper refining to high purity

Learning activity # 5

Title of Learning Activity: Nuclear chemistry

Summary of the learning activity

On completion of this Unit, the learner should be able to:

- Explain and describe the nature of radioactivity
- Identify the different types of radioactive emissions and the properties of the emitted radiation
- Carry out calculations using the radioactive decay law
- Explain the relation between mass and energy and solve problems relating to mass-energy equivalence

Nuclear chemistry deals with processes that take place at subatomic level. All elements originate from the stars including the sun where heavier elements are formed from lighter ones through fusion reactions. Examination of the elements found in the periodic table shows that elements with atomic number greater than 83 are unstable and undergo radioactive decay. However, some of lighter elements also exhibit the phenomenon of radioactive decay. The learner will study the different forms of radioactive decay and what factors influence whether an element is more likely to be radioactive or not. Elements decay by emitting alpha, beta or gamma radiation. Each type of emitted radiation has characteristic properties some of which can be harnessed for use in specific applications such as nuclear medicine, analytical techniques, or power generation. Another very useful application of the radioactive decay phenomenon is the radiocarbon dating technique that enables the estimation of historical artefacts.

List of REQUIRED readings

- An Introduction To Radioactivity
- Nuclear Chemistry

List of relevant useful links

Nuclear Chemistry: An Introduction

http://www.visionlearning.com/library/module_viewer.php?mid=59

Nuclear Chemistry And The Origins Of The Elements

http://www2.wwnorton.com/college/chemistry/gilbert/tutorials/ch2.htm

Radiation And Radioactivity

http://www.physics.isu.edu/radinf/cover.htm

Nuclear Chemistry

http://www.bcpl.net/~kdrews/nuclearchem/nuclear.html

List of relevant MULTIMEDIA resources

- Computer with internet connectivity to enable access to open source learning materials and interactive learning through email, video conferencing and use of CD-ROMs
- QuickTime Movie Player Software
- Shockwave Player Software
- Macromedia Flash Player Software

Formative evaluation

- As you make your way through this learning activity you will come across problems to test your conceptual understanding of the subject matter
- Rapid quizzes are provided to check your understanding
- Practical experiments will be given to evaluate your understanding of theory-practice relations
- Simulated experiments/exercise will be given to test your understanding of certain concepts

Learning activities

In conventional chemical reactions, interactions involve valence electrons around the nucleus. In contrast, nuclear reactions are concerned with reactions associated with the nucleus. It deals with nuclear processes and properties. The nuclei of most elements are stable and oblivious of what is happening at the 'surface' of the atom. However, some isotopes are unstable resulting in emission of radiation with properties that are both useful but also dangerous. In this unit we shall examine the origins and properties arising from nuclear reactions.

5.1 Phenomenon of radioactivity

Elements that are unstable disintegrate and release high-energy streams of electromagnetic radiation. Such isotopes are radioactive and exhibit a phenomenon known as radioactivity. Nuclear reactions result in transmutation of one element into a different isotope or indeed different element. Three nuclear changes and radiation types may occur. These are discussed in sections that follow.

5.2 Types of radiation

Radiation may be classified as either particulate (consisting of particles) or non-particulate (electromagnetic). Both particulate and non-particulate radiation has adverse and positive aspects. It is important to understand the properties of the different forms of radiation to be able to use them judiciously and appropriately.

5.2.1 Alpha radiation (α)

Alpha radiation is the emission of a stream of nuclei of helium atoms symbolized by ${}^{4}_{2}\mathrm{He}^{2+}$.

The atomic mass of an atom decreases by four atomic mass units when it emits an alpha particle. An element is said to *'transmute'* into another element. A typical example showing such a nuclear reaction is the transmutation of uranium into the element thorium by emission of an alpha particle.

$${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

Omission of the charge in the species focuses attention on the nucleus unlike other area of chemistry, which focus on the outer electrons.

The rules for balancing nuclear reactions differ from those in conventional reactions. A nuclear equation conforms to two rules. That the

- sum of mass numbers must be the same on both sides
- sum of atomic numbers must be same on both sides

Characteristics

Alpha particles produce a large number of ions through their collisions and near collisions as they pass through matter. They are of low penetrating power and are stopped by a sheet of paper. They are positive and are deflected by electric and magnetic fields.

5.2.2 Beta Particles

The simplest processes involve decay of a free neutron, which is unstable outside the nucleus of the atom.

$${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + \nu \qquad \nu \text{ is an entity called neutrino}$$

During beta emission, there is no change in the mass of the atom since the nuclear particles remain the same but the atomic number changes. The atomic number increases by one since one neutron, changes into a proton. A typical example is the decay of the carbon isotope carbon-14 into the element nitrogen.

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Characteristics

- Deflected on opposite direction to α particles in electric and magnetic fields
- Smaller and therefore deflected more strongly than α particles
- Essentially electrons but ones that originate from the nuclei of atoms undergoing nuclear decay

A similar process can take place that involves the conversion of a proton to a neutron and a positron. Positron emission is commonly found in artificially induced radioactive nuclei of the lighter elements.

$${}^{30}_{15}P \rightarrow {}^{30}_{14}Si + {}^{0}_{+1}\beta$$

5.2.3 Gamma Rays (γ)

Gamma radiation is emitted during alpha or beta decay. The radioactive decay process yielding α or β particles leave a nucleus in an excited state. The nucleus then loses some of that energy in form of electromagnetic radiation. These are penetrating and are not deflected by either a magnetic field or electric field. A typical example the decay of ${}^{234}_{92}\text{U}$

$${}^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

$${}^{230}_{90}\text{Th} \rightarrow {}^{230}_{90}\text{Th} + \gamma\text{-rays}$$

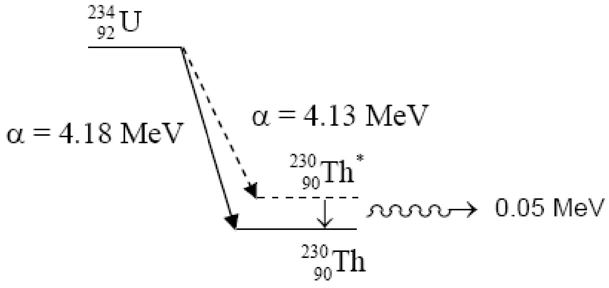


Figure 5.1 Illustration of the production of gamma radiation following an alpha emission

Example problem 1

Write the nuclear equation to represent the alpha emission of ^{222}Rn.

Solution

This requires knowledge of the concept of balancing nuclear equations. For the given problem the nuclear equation can be written as:

$${}^{222}\text{Rn} \rightarrow \text{X} + {}^{4}_{2}\text{He}$$

Since the alpha particle contains two protons, X must have two protons less than the element ${}^{222}_{86}\text{Rn}$ i.e. 86-2= 84. Our periodic Table will show that the element with atomic number (Z) 84 is polonium, ${}_{84}$Po. To establish the mass number (A), we subtract the mass number of the alpha particle i.e. 222 – 4= 218. We can now complete the nuclear equation as

$${}^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

Practice problem 1

What is X in the nuclear equations shown below?

$^{9}_{4}\text{Rn} + ^{1}_{1}\text{H} \rightarrow ^{6}_{3}\text{Li} + \text{x}$

$^{208}_{82}\text{Pb} + \text{x} \rightarrow ^{265}_{108}\text{Hs} + ^{1}_{0}\text{n}$

$^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + \text{x}$

5.3 Naturally occurring radioactive isotopes

Several isotopes of natural occurring elements are radioactive. For example, naturally occurring $^{238}_{92}\text{U}$ is radioactive and disintegrates by the loss of α particles.

$$^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + ^{4}_{2}\text{He}$$

Rutherford discovered that bombarding $^{14}_{7}\text{N}$ with α particles produced $^{17}_{8}\text{O}$ and protons

$$^{14}_{7}\text{N}+^{4}_{2}\text{He}\rightarrow^{17}_{8}\text{O}+^{1}_{1}\text{H}$$

The reaction does not occur spontaneously but it must be struck by another particle ($^{4}_{2}\text{He}$) to disintegrate - induce a nuclear reaction. The Curies discovered that bombardment of aluminium leads to emission of two particles: neutrons and positions. They also observed in their experiments that when bombardment stopped, α-particles emission stopped but positron emission continued. They concluded therefore that phosphorus decays by emission of positions.

$$^{27}_{13}\text{Al}+^{4}_{2}\text{He}\rightarrow^{30}_{15}\text{P}+^{1}_{0}\text{N}$$

$$^{30}_{15}\text{P}\rightarrow^{30}_{14}\text{Si}+^{0}_{+1}\beta$$

The first element produced in this manner was $^{30}_{15}\text{P}$ and many more have since been made.

5.4 Transuraurum elements

In 1940, the first synthetic element $^{239}_{92}U$ was produced by bombarding $^{238}_{92}U$ with neutrons. Bombardment using neutrons is effective in producing nuclear reactions because the heavy particles are not repelled as they approach the nucleus. Many elements have also been produced using heavy-atom bombardment. For example, an element as nitrigen is bombarded with nuclei of lighter elements such.

$$^{249}_{98}Cf + ^{15}_{7}N \rightarrow ^{260}_{105}Ha + 4^{1}_{0}n$$

5.5 Rate of Radioactive Decay

In a sample of material containing radioactive elements every nucleus is expected to disintegrate at some point but one cannot predict when it will disintegrate. We can however use statistical methods to make predictions for a collection of atoms. From experiments, the rate of disintegration of a radioactive substance is directly proportional to the number of radioactivity nuclei, N. The established radioactive decay law is stated as follows:

"The rate of disintegration of a radioactive material called the activity, A, or decay rate –and is directly proportional to the number of atoms present.

We can write in mathematical terms that

Rate of decay (A) α N

$$A = \lambda N$$

where A is the activity and has units of atoms/unit time, N is number of atoms in the sample being observed and λ is the decay constant with units of time^{-1}. Radioactivity is a first-order process. We can visualize activity as if it were a rate of a chemical reaction where N corresponds, to concentration of reactant and λ corresponds to the rate constant. For a process following first order kinetics the following integrated rate and half-life, equation can be written.

$$\ln \frac{N_t}{N_0} = -\lambda t \qquad (5.1)$$

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda} \qquad (5.2)$$

N_o is the number of atoms at initial time (t = 0) and N_t the number of atoms at a later time, t. The half-life is defined as before, the length of time required for half the amount of substance to disappear. Recall that for a first order process the half-life is a constant. It follows that the shorter the half-life, the larger the value of λ and the faster the decay process. Half-lives for radioactive elements vary - from extremely very short to very long.

Example 1

Calculate the number of disintegrations per second that occur in 100 g of radium given that the decay constant is 1.36 x 10^{-11} radium?

The rate of radioactive decay is given A = λN

where λ is the number of disintegrations per second and N is the number of atoms present. We begin by calculating the number of atoms present

$$\text{No. of moles} = \frac{100\ \text{g}}{226\ \text{g mol}^{-1}} = 0.442\ \text{moles}$$

We know that in 1 mole there are 6.02 x 10^{23} particles, therefore the number of particles (N) in 100 g or 0.442 moles is

N = 6.02 x 10^{23} atoms/particle x 0.442 moles = 2.66 x 10^{23} atoms

The number of disintegrations therefore is

A = λN

= 1.36 x $^{-11}$ x 2.66 x 10^{23} atoms

= 3.62 x 1012 disintegrations sec^{-1}

5.6 Radiocarbon dating

The phenomenon of radioactivity provides a useful tool for establishing the age of fossil remains. The principle behind the determination is based on the following. In the upper atmosphere $^{14}_{6}\text{C}$ is being formed continuously by bombardment with neutrons of $^{14}_{7}\text{N}$. Neutrons being produced by cosmic rays.

$$^{14}_{7}\text{N} + {}^{1}_{0}\text{n} \rightarrow {}^{14}_{6}\text{C} + {}^{1}_{1}\text{H}$$

Carbon containing compounds in living organisms maintain equilibrium with ^{14}C in the atmosphere. Organisms replace ^{14}C atoms that have undergone radioactive decay with fresh ^{14}C atoms through interaction with the environment. The equilibrium is destroyed once an organism no longer interacts with the atmosphere (e.g. through breathing air). The disintegration rate therefore falls off with time.

Measurement of disintegration rates at a later stage enables us estimate of the age artefacts.

Example 2

Two students scouring an archaeological site found what appeared to be fossil remains. The specimen was found to have a ratio of $^{14}C/^{12}C$ 0.795 times that found in current living plants. What would be the estimated age of the fossil remains? The half-life for carbon -14 is 5720 years.

Solution

Radioactive decay is first order process as indicated in equation (5.1)

$$\ln \frac{N_t}{N_0} = -\lambda t$$

$$e = \frac{0.693}{7520\ yr^{-1}} = 1.21\ x\ 10^{-4} yr$$

To be able to use the above equation we need to find λ. This can be calculated from the equation

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Since $t_{\frac{1}{2}} = 5720$ years we can calculate λ, $\lambda = \frac{0.693}{7520\ yr^{-1}} = 1.21\ x\ 10^{-4} yr$

The integrated rate law can be written as

$$\log \frac{N}{N_0} = \frac{-1.21 x 10^{-4}\ yr^{-1}}{2.303} x\, t$$

N_0 is the amount of substance at time zero and N the amount time at a later time, t. N can be estimated to be $N = 0.795N_0$ or $N/ N_0 = 0.795$, hence

$$\log \frac{1}{0.795} = \frac{-1.21\ x 10^{-4}\ yr^{-1}}{2.303} x\ t$$

$$-\ 0.100 = -\ 5.25\ x\ 10^{-5}\ yr^{-1}\ x\ t$$

$$t = 1895\ yr$$

$$t = 1900\ yr$$

Practice problem 2

Counting the number of rings on a tree trunk gives an estimate of the age of a tree. A specimen under study by a group of students using this method estimated the age to be 7, 000. In a radiocarbon dating experiment, the specimen was found to have an activity of 6.6 disintegrations per second per gram of carbon. Use the technique of carbon dating to estimate the age of the wood. **(Answer: 6225 years)**

5.7 Mass-energy equivalence

The relationship between mass and energy is through Einstein's mass-energy equation.

$$E = \Delta mc^2 \qquad (5.3)$$

where E is the energy change, Δm the change in mass and c is the speed of light. The equation implies that a small amount of mass changes into a large amount of energy.

Take for example the formation of $^{4}_{2}\mathrm{He}$ from two neutrons and two protons. The experimental mass is less than the theoretical mass. This suggests that some of the mass has been lost. The difference in mass is the *mass defect*. Mass does not disappear but is converted into energy.

5.7.1 Binding energy

The nucleus of an atom consists of protons and neutrons, the former being positively charged and the latter being neutral. The presence of like charges is not energetically favourable. The nucleons should be flying apart due to electrostatic repulsions. So how is it that the nucleons do not fly apart? Some energy must be used to counter-act the nucleons not to spontaneously do so. This energy is the nuclear binding energy. Where does the binding energy come from?

Consider the example of the formation of the $^{4}_{2}\mathrm{He}$ particle.

Mass of two protons = 2 x 1.00727646 amu = 2.01455292 amu
Mass of two neutrons = 2 x 1.00866492 amu = 2.01732984 amu

Total mass = 2.01455292 amu + 2.01732984 amu = 4.03188276 amu

The actual mass of ^{4}He (4.00260324 amu) is less than the sum of the protons and neutrons. The missing mass is 0.02927952 amu.

$$0.02927952 \text{ amu} \times \frac{1.66053873 \times 10^{-27} \text{ kg}}{1 \text{ amu}} = 4.8619776 \times 10^{-29} \text{ kg}$$

The energy equivalence, which is the binding energy, is obtained by substitution in $E = \Delta mc^2$.

Binding energy = $4.8619776 \times 10^{-29}$ kg x $(3.0 \times 10^8 \text{ m s}^{-1})^2$

= $4.3697275 \times 10^{-12}$ J

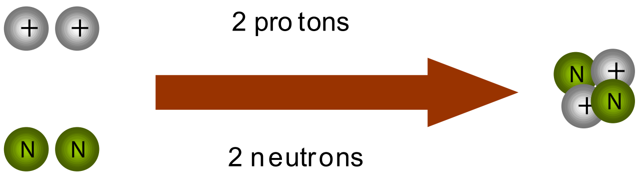


Figure 5.2 Illustration of the formation of an alpha particle from 2 protons and 2 neutrons to form a helium particle.

Important Units

- Energy from previous equations is in Joules (J)
- Another common unit is electron volt

  1 eV = 1.60022×10^{-19}J

  1 MeV = 1.6022×10^{-13}J

- Conversion factor between atomic mass units (u) and Joules

  1u = 1.6606×10^{-24}g

  From $E = mc^2$

$$= 1\,\text{u} \times \frac{1.6606 \times 10^{-24}}{10^3}\,\text{kg} \times (2.9979 \times 10^8)^2 \text{m}^2\text{s}^{-2}$$

= 1.4924×10^{-10}J

Energy equivalent of 1u

1 atomic mass unit (u) = 1.4924×10^{-10}J

1 atomic mass unit = 931.5 MeV

5.7.2 Binding energy and nuclear stability

The binding energy per nucleon can be calculated for the different elements i.e. dividing the binding energy by the number of nucleons. A graph of binding energy per nucleon provides useful information on the stability of elements. Figure 5.3 shows the variation of binding energy per nucleon against mass number.

The graph shows the binding energy increasing with increasing mass number reaching a maximum at Fe-56. Thereafter the energy decreases. This data suggests that the nucleons in Fe are the most tightly bound and therefore the iron isotope is the most stable and less likely to break-up. The elements in the vicinity will break up or combine to yield nuclei that are more tightly bound. The elements before Fe release energy when fused whilst those that are post Fe, yield energy by breaking up - fission. The decrease in binding energy post Fe is attributable to the growing size of the nucleus, as the nucleus gets bigger the ability of the binding force becomes weaker to counter-act the electrostatic forces between the protons.

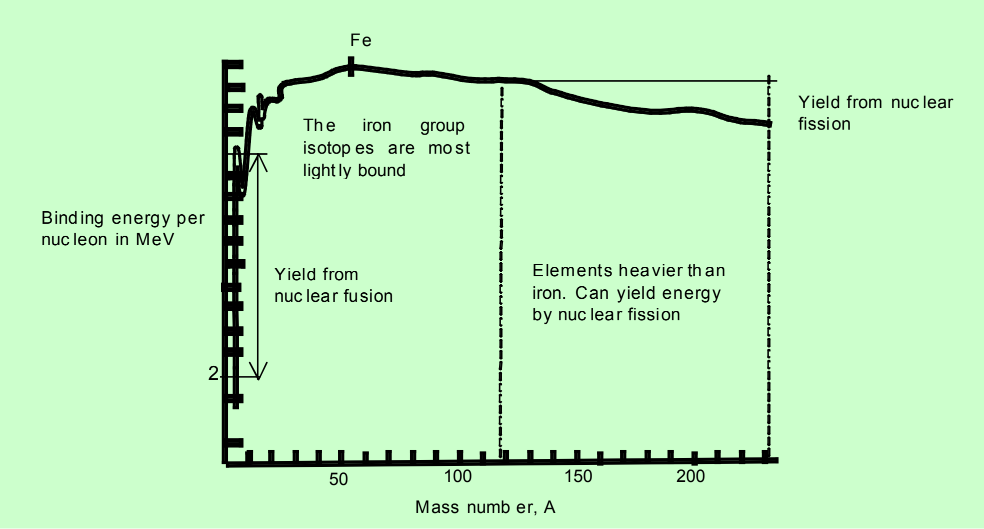


Figure 5.3 Variation of binding energy against mass number of elements in the periodic table. Plot shows areas likely to undergo decay by fission and fusion.

*Adapter from http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/nucstructcon.html#c1

5.8 Magic numbers

The stability of elements is also influenced by the ratio of protons to neutrons. Nuclei that contain either too many or too few neutrons are unstable. One observation is that stability of the nuclei occurs more in nuclides that have even numbers of protons. A comparison can be made between stable electronic configuration magic numbers 2, 8, 18, 36, which are unusually stable. Similar magic numbers of protons in nuclei with 2, 8, 20, 28, 50, 82, or 126 protons or neutrons are unusually stable. A nucleus will attempt to attain stability by getting rid of nucleons, as well as other particles, or by releasing energy in other forms.

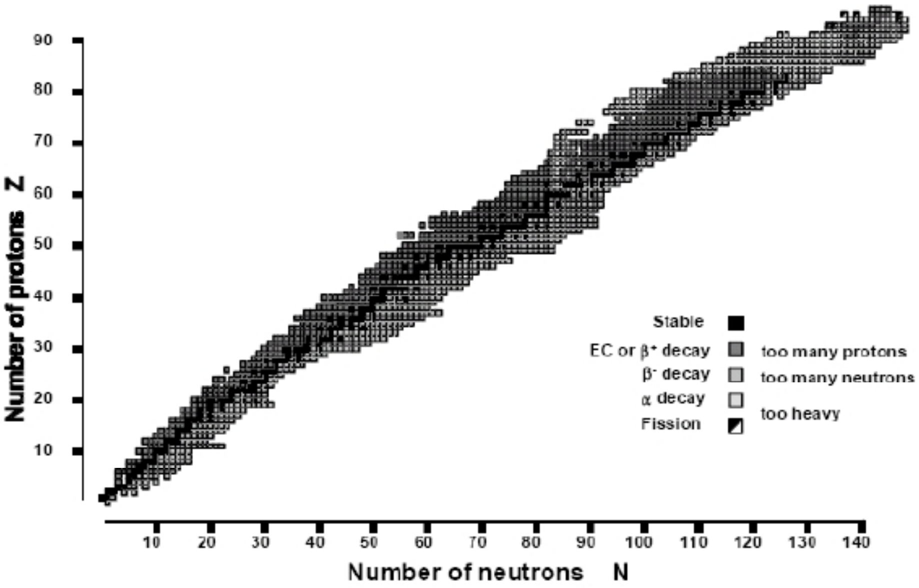


Figure 5.4 Plot showing the distribution of nuclei in relation to the number of protons and neutrons. A stability band is clearly visible with possible decay on either side of the band.

*Diagram adapter from http://www.e-adiography.net/articles/Introduction%20to%20Radioactivity.pdf

The Figure 5.4 shows the stability band for various proton/neutron ratios that give rise to measurable half-lives. The emission characteristics of nuclei depend on which side of the stability band they are. Nuclides with lower proton/neutron ratio tend to undergo positron emission, electron capture or alpha emission. On the other hand, the nuclei with high proton/neutron ratios tend to go by beta emission.

5.9 Interaction of radiation with matter

Radiation such as alpha, beta and gamma rays are examples of ionising radiation owing to their ability to knock off electrons as they pass through matter. Radiation may also raise the energy of of the electrons to a higher level during their interaction. The general trend in ionizing power is α particle > β particle > x-rays. Applications of radiation makes use of the nature of the interaction of various types of radiation with matter. In the sections that follow we shall examine how different forms of radiation interact with matter.

Alpha particles

Alpha particles are comparatively heavier particles (2 protons and 2 neutrons) and also carry a double charge. Consequently, they tend to cause significant ionization as they collide with electrons on the atoms knocking them off, in some cases causing excitation. The particles are not deviated from their path following a collision owing to their heavy weight. However, the particle loses some energy in each succesive collision causing it to slow down. In the event where they happen to collide with a nucleus, the alpha particle is diverted sigificantly from its path whilst the nucleus recoils in another direction. The alpha particle eventually comes to a halt following many collisions. The penetration range, distance travelled before stopping, depends on particle's energy and the material involved. The interaction between an alpha particle and matter is shown graphically in the diagram below.

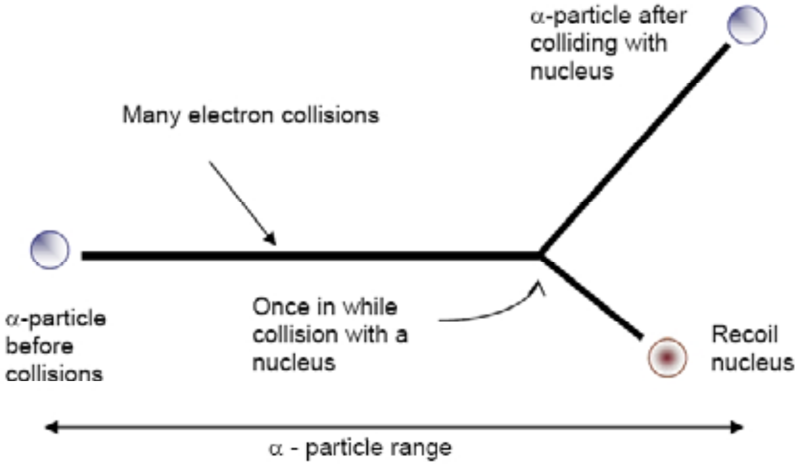

α-particle after colliding with nucleus
Many electron collisions
α-particle before collisions
Once in while collision with a nucleus
Recoil nucleus
α - particle range

Figure 5.5 Interaction of an alpha particle with matter. Diagram shows the types of interaction and processes that result.

Beta particles

Beta partcles are expected to cause less ionisation compared to the alpha particles owing to their lighter size and the fact that they carry a single charge. They produce less dense ionisation. Deviation is more pronounced as they pass through matter causing ionisation in the process. The electron-beta particle collision causes the beta particle to deviate at a large angle while the electron it colideds with, called a delta ray, gains sufficent energy to move off on its own. The delta ray goes on to produce more ionisation. The occassional encounter with an atomic nucleus (high atomic number) causes a violent deviation giving off what are known as ***bremsstrahlung*** X-rays. The particle then follows a zig-zag path unitl eventually it comes to a standstill. The beta particles have a longer range than alpha particles since they produce less dense ionisation (loss energy) and slow down more gradually than the alpha particles.

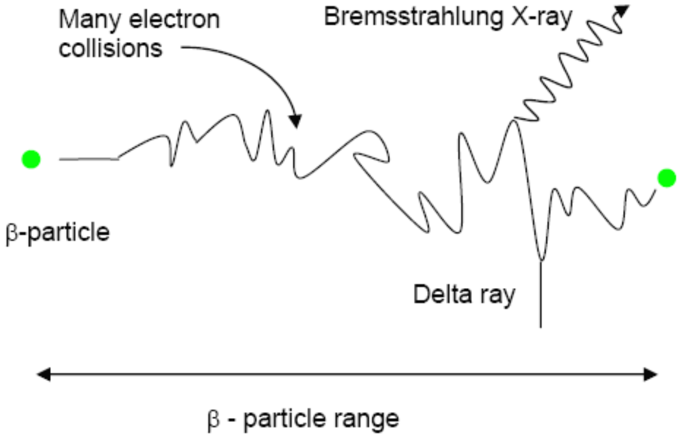


Figure 5.6 Interaction of an beta particle with matter. Diagram shows the zig-zag path taken by the particle through matter.

Gamma and X-rays

Gamma and X-rays are different from α and β radiation in that they are non-particulate in nature. These are electromagnetic radiation. Gamma and X-ray interaction with matter occurs in a very limited manner if any interaction takes place at all. Their interaction is essentially through secondary electrons that are produced as they pass through. Two types of prcesses are identified: scattering and absorption.

(i) Compton scattering

Compton scattering occurs when a gamma ray interacts with a free electron in a material. Some of the energy of the gamma ray is transferred to the electron, the other part contiunes as scattered radiation. The scattered radiation is of lower energy and deviates from its original path.

(ii) Photoelectric absorption

Photoelectric absorption takes place when a gamma ray gives up all its energy at once to a free atomic electron which is then ejected from the atom. The second type of absorption involves gamma rays with energy which is greater than 1 MeV. In this case the absorption leads to the production, smultaneously, of an electron and positron. The positron subsequently being anihilated with an atomic electron. The anhilation process leads to the production of two gamma rays of 511 MeV energy.

The gamma and X-rays as described in previous section encounter very few interaction hence have no definite range. An alternative method to assess its penentration range is used. The half-value layer, the distance required to half the number of gamma rays, is used. synonymously to the half-life used in radioactive decay.

XI. Compiled List Of All Key Concepts (Glossary)

Key Term And Concepts

Alpha particle (α) is a particle emitted during radioactive decay of certain atomic nuclei comprising two neutron and two protons. It is identical to the helium ion, ${}^{4}_{2}He^{2+}$.

Anode is the electrode in an electrochemical cell at which an oxidation half reaction takes place.

Association colloids are systems in which the dispersed phase consists of clusters of molecules that have lyophobic and lyophilic parts.

Beta particle (β) is an electron emitted during the conversion of a neutron to proton in certain atomic nuclei undergoing radioactive decay.

Boiling point is the temperature at which the saturated vapour pressure of a liquid equals the external atmospheric pressure.

Bremmsstrahlung x-rays are X-rays emitted when a charged particle, especially a fast electron, is rapidly slowed down.

Cathode is the electrode in an electrochemical cell where a reduction half reaction takes place.

Cell potential (E_{cell}) is the potential difference between two electrodes of an electrochemical cell.

Change in free energy (ΔG) is the change in free energy that accompanies a process.

Chemical potential (μ) for a given mixture is the coefficient $\delta G/ \delta n$ where G is the Gibbs free energy and n is the number of moles substance of the component. It is the change in Gibbs free energy with respect to amount change in amount of the component.

Coagulation is process upon which colloidal particles come together irreversibly to form larger particles.

Colligative properties have values that depend only on the number of solute particles in a solution and not the identity. Examples include osmotic pressure, boiling point elevation and freezing point depression.

Colloid system is dispersion with particles that are intermediate in size between a true solutions and an ordinary heterogeneous mixture.

Compton scattering occurs when high energy photons are scattered by free electrons thereby gaining energy.

Diffusion is the process by which different substances mix because of random motion of the component atoms, molecules, or ions.

Electrochemical cell is device in which electrons transferred in an oxidation-reduction reaction are made to pass through an external circuit.

Electromotive force (emf) is the potential difference between two electrodes in voltaic cell expressed in volts (V).

Eutectic mixture is a solution consisting of two or more substances and having the lowest freezing point of any mixture possible of these components.

Eutectic point is the minimum freezing point for a set of components in eutectic mixture

Faraday's constant (F) is the electric charge carried by one mole of electrons or singly charged ions, F = 96 500 C/mol.

Fractional crystallisation is a method of purifying a substance by crystallising the pure solid substance from a saturated solution leaving the impurities in solutions.

Fractional distillation is distillation in which components of a liquid solution are separated based on their volatilities.

Free energy (G) is a thermodynamic function designed to produce a criterion for spontaneous change, $G = H - TS$.

Freezing point is temperature at which a liquid changes to a solid.

Galvanic (voltaic) cell is an electrochemical cell in which spontaneous reactions produce electricity.

Gamma rays (γ) are electromagnetic radiation produced when an excited atomic nucleus returns to a lower state of excitation.

Gibbs phase rule states that for any given system at equilibrium, the relationship $P + F = C + 2$ is true where P is the number of distinct phases, C is the number of components and F is the number of degrees of freedom of the system.

Half-life in radioactive process is the time required for half the number of atoms present to undergo radioactive decay.

Henry's law relates the solubility of a gas to the gas pressure maintained above a solution of the gaseous solute $C = kP_{gas}$.

Ideal solution are solutions that obey Raoult's law.

Magic numbers is the term used to describe the neutron and proton numbers that give atomic nuclei special stability.

Melting point is the characteristic temperature at which a solid changes into a liquid.

Molal concentration (m) is the solution concentration expressed as amount of solute in moles divided by mass of solvent in kg.

Molality (*m*) is the amount of substance per unit mass of solvent, commonly used units, mol kg^{-1}

Nernst equation relates the cell potentials E°, E_{cell}^{0} and the activities of the reactant and products in a cell reaction.

Nuclear binding energy is the energy required to pull apart neutron and protons in an atomic nucleus.

Nuclear equation is a representation of the changes that occur during a nuclear process.

Osmosis is the net flow of solvent molecules through a semipermeable membrane, from a more dilute solution into a more concentrated solution.

Osmotic pressure (Π) is the pressure that would be required for a solution to stop passage through a semipermeable membrane. The osmotic pressure is given by $\Pi V = nRT$ where n is moles in volume V, R is the gas constant and T the absolute temperature.

Phase diagram is a graph that indicates the relationship between solid, liquid and gas gaseous phases over a range of conditions, usually temperature, and pressure.

Phase is a homogeneous part of a heterogeneous system that is separated from other parts by a distinguishable boundary

Photoelectric absorption takes place when gamma rays interact with free electrons giving up all its energy at once and the electron is ejected from the atom.

Radioactive decay constant (k) is the proportionality constant in the radioactive decay law

Radioactive decay law states that the rate of radioactive decay (A) is directly proportional to the number of atoms present.

Raoult's law states that the vapour pressure of a solution component is equal to the product of the vapour pressure of the pure liquid and its mole fraction in solution,

$$P_A = X_A P_A^{\circ}$$

Salt bridge is a device used to join two half-cells in an electrochemical cell.

Standard electrode potential (E°) is the potential that develops between on an electrode when the oxidized and reduced forms of substances are in their standard states.

Standard hydrogen electrode (SHE) is an electrode at which equilibrium is established between the hydronium ion, H_3O^+ (a = 1) and H_2 (g, 1 atm) on a platinum surface.

Triple point is the condition of temperature and pressure at which all three phases (usually solid, liquid and gas) of a substance exists at equilibrium.

Viscosity is the liquids resistance to flow whose magnitude depends on intermolecular forces of attraction, in some instances size and shape

XII. Compiled List Of Compulsory Readings

Reading #1

SOLUTION

Complete reference : A Chem1 Reference Text

http://www.chem1.com/acad/pdf/solut.pdf

Abstract : The text covers the topic of solutions in a general way. Begins by examining the different types of solutions and then followed with different methods of concentration measurements. Colligative properties osmotic pressure, freezing point depression and boiling point elevation are also discussed

Rationale : This text is an easy to read reference, which is ideal for the study of Unit I. The text has a number of well-elaborated diagrams to explain concepts making it easier to grasp them. A number of example problems are given in each of the topics to further amplify and show application.

Reading #2

SOLUBILITY

Complete reference: http://en.wikipedia.org/wiki/Solubility

Access date: 16 October 2007

Abstract : This is a brief overview of various aspects of solubility. The text gives a molecular view of solubility and factors that influence the solution process such as polarity of molecules, temperature, and pressure. Keywords are hyperlinked to provide immediate references. Quantification is also briefly touched.

Rationale: The fundamental view of the concept of solubility is given in this reading. This is essential for revision prior to studying the unit on solutions. It provides the essentials together with links for explanations of key terms.

Reading #3

COLLOIDS

Complete reference: http://mysite.du.edu/~jcalvert/phys/colloid.htm

Access date: 18 October 2007

Abstract: The topic colloids are covered comprehensively in a qualitative manner. Different types of colloidal systems and their properties are discussed. The purification of colloids using the osmosis and dialysis is also looked at. It contains several examples of colloidal systems.

Rationale: The text gives a broad qualitative view of the topic covered in Unit II. It not only explains colloids from a chemical point but also gives illustrations of daily encounters that allows the learner greater appreciation of these systems.

Reading # 4

Complete reference : http://en.wikipedia.org/wiki/colloid

Access date: *18 October 2007*

Abstract: Colloids are covered in a brief and in concise manner. Classification with examples of different types colloids are given. Factors leading to colloidal stability are discussed and so are those that can lead to the break down the system.

Rationale: This Wiki text is a brief outline of the topic of colloids that the learner encounters with hyperlinked important terms. This is ideal for quick revisions and reminder of the topics in the Unit..

Reading # 5

PHASE EQUILIBRIUM

Complete reference : http://www.wpi.edu/Academics/Depts/Chemistry/Courses/General/concep10.html

Access date: 18 October 2007

Abstract: This reading is a chapter taken out the online textbook for General Chemistry program at WPI. Has comprehensive coverage of thermodynamics before looking at phase equilibrium. Various types of phase equilibria are dealt with using numerous examples to illustrate concepts. A number of phase diagrams for selected systems are also discussed.

Rationale: Thermodynamics is an important topic required for studies involving phase equilibria. The text begins by looking at disorder and spontaneity of process. This reading provides both the basis and development in studying Unit III of this module. The examples given allow that learner have a feel of the application in various concepts.

Reading # 6

PHASE EQUILIBRIUM AND INTERMOLECULAR INTERACTIONS

Complete reference : http://cnx.org/content/m12596/latest

Abstract: This text focuses mainly on gas-liquid equilibrium, vapour pressure and the associated phase diagrams. The difference between gases and the condensed phase is described. It goes on to describe the transitions between the solid, liquid and gas phases. The role of intermolecular forces in the transitions is also examined

Rationale: This reading enables the learner to make meaningful linkage with topics leaned earlier relating on kinetic molecular theory to phase equilibria, the subject of Unit III. Additionally, the concept of dynamic equilibrium is brought in which is not directly addressed in the module.

Reading # 7

ELECTROCHEMISTRY

Complete reference : Chem1 Virtual Textbook

http://www.chem1.com/acad/webtext/elchem/

Abstract: This is an excellent reading, which is part of Chem1 Virtual Textbook. It systematically develops the topic of electrochemistry starting with the phenomenon of charge transfer as takes place at a metal-liquid interface. The concept of electrode potential is examined leading to electrochemical cell. The link between free energy and cell potential is made through the Nernst equation

Rationale: This reading is intended for use in studying Unit IV of this module. It covers all the major aspects of electrochemistry including its applications. The learner does not only get to grasp the theoretical concepts but also its application in everyday life. The text in interfaced with problem examples to illustrate concepts.

Reading # 8

ATOMIC NUCLEI

Complete reference : A Textbook for High School Students Studying Chemistry

Abstract: This is a free textbook intended for high school chemistry. It covers nearly all the major topics of chemistry including atomic structure and nuclear chemistry. Nuclear forces are discussed and the nature of radioactive decay examined (alpha, beta and gamma). The chapter ends with applications of nuclear reactions i.e. nuclear reactors.

Rationale: This reading is advisable for one who has not come across the topic before. It comes all the topics in nuclear chemistry in an elementary manner which is suitable for tackling Unit V of this module. It is good foundation reading for Unit V

Reading # 9

INTRODUCTION TO RADIOACTIVITY

Complete reference :
http://www.e-radiography.net/articles/Introduction%20to%20Radioactivity.pdf

Abstract: The reading begins by giving a historical perspective of the radioactivity phenomenon. Units essential for studying the radioactivity phenomenon are introduced. The nature of the atomic nuclei is discussed followed by factors that lead to nuclear stability or instability. The type of radiations arising from nuclear decay and the nature of its interaction with matter are examined.

Rationale: Unit V deals with the chemistry that occurs at subatomic levels, which are accompanied by the emission of radioactivity. This reading is a comprehensive presentation of nuclear reactions. It is an essential reading for the unit on nuclear chemistry. The sections on the interaction of matter and radiation alert the learner to the dangers of radiation.

XIII. Compiled List of (Optional) Multimedia Resources

Resource #1

Complete reference : Chemistry@Davidson

http://www.chm.davidson.edu/ChemistryApplets/index.html

Abstract : This resource has experiments and exercises that are animated and interactive. The experiments are well tabulated, accompanied with a short summary and are interactive.

Rationale: The interactive experiments assist the learner on the application of concepts covered in the respective Units. The learner must attempt these exercises to gauge how well they have understood the Unit.

Resource #2

Complete reference : Chemodule

http://www.karentimberlake.com/chemodul.htm

Abstract : In this is resource are a series of mini-lectures that in power point form. The ppt lectures can used for self-paced study as well reviewing materials just learned. Quizzes accompany the lectures enabling the learner to self-evaluate how well the concepts have been grasped.

Rationale: Mini-lectures relating to Unit I and Unit V can be found here. Additionally, pre-requisite content necessary for tackling topics in the module are also available. Quizzes on each of the topics allow assessment either during the learning process or after.

Resource #3

Complete reference: Virtual lab Simulation

http://www.chemcollective.org/applets/vlab.php

Abstract: Virtual lab allows the learner to carry out simulated experiments giving the learner a feel of a laboratory practical. The learner has access to wide range of chemicals, glassware and instruments that the learner can use to execute a particular experiment.

Rationale: The simulated experiments are important for illustrations of concepts that have touched in the various learning activities. The learner can design and carry out experiments relating to thermochemistry, solubility, and electrochemistry. The learner can pick suitable glassware and instruments such burners and pH meters.

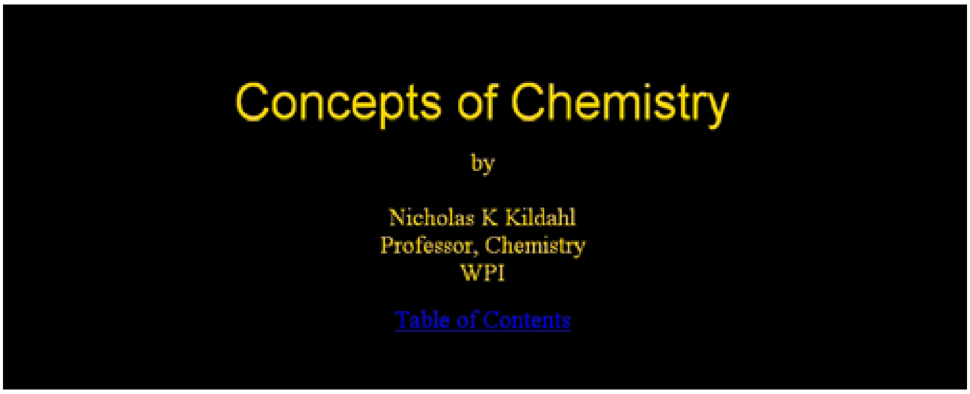
XIV. Compiled List of Useful Links

Useful Link #1

Title : Concepts Of Chemistry

URL : http://www.wpi.edu/Academics/Depts/Chemistry/Courses/General/conceptt.html

Screen capture :



Concepts of Chemistry

by

Nicholas K Kildahl
Professor, Chemistry
WPI

Table of Contents

Description: This website is a collection of online chapters in chemistry. The topics are well organised with a Table of Contents that allows the learner to easily access the desired materials. It also contains useful hyperlinked Appendices for tools for energy conversion units, dimensional analysis, thermodynamic data and others

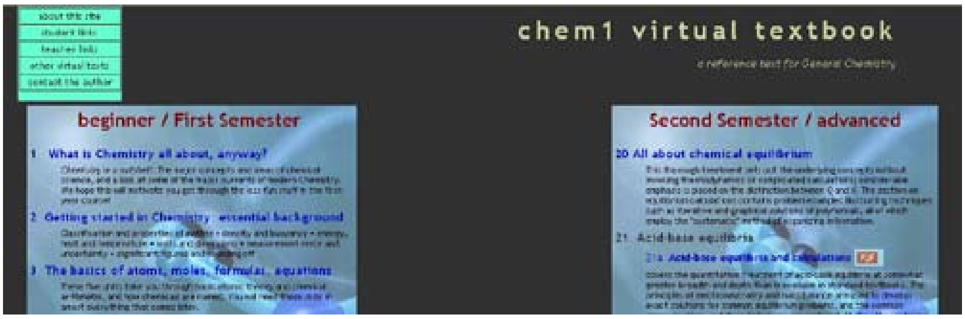
Rationale: Many of the topics that will be encountered in this module require supplementary reading. This website provides a single point to access and gain requisite knowledge for studying the module. The following topics: intramolecular and intermolecular forces and molecular energy, solid and liquid phases and disorder changes in physical and chemical processes are worth noting. These topics are important to studying Unit I.

Useful Link #2

Title : Chem1 Virtual Text Book

URL : http://www.chem1.com/acad/webtext/virtualtextbook.html

Screen capture :



chem1 virtual textbook

a reference text for General Chemistry

beginner / First Semester

1 What is Chemistry all about, anyway?

2 Getting started in Chemistry essential background

3 The basics of atoms, moles, formulas, equations

Second Semester / advanced

20 All about chemical equilibrium

21 Acid-base equilibria

Description: The Chem1 virtual textbook is a reference text for general chemistry. It covers several essential chemistry topics with good illustrations and exposition of chemical concepts. The site contains many downloadable topic chapters in PDF format.

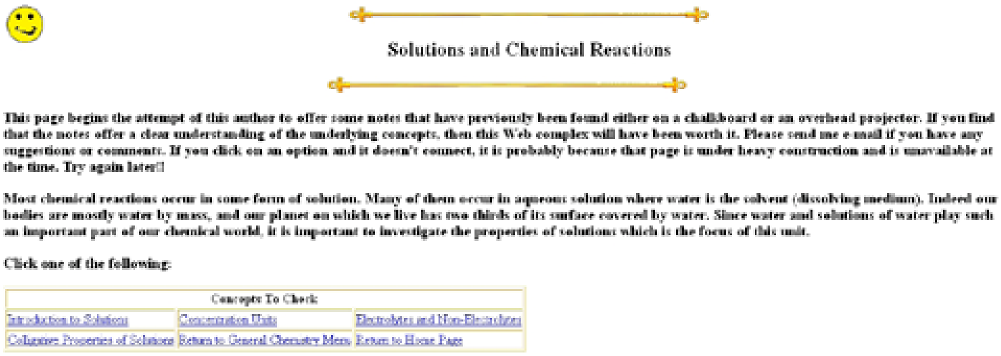
Rationale: The learner is able to either use this resource online or download a desired PDF file. The main Chapters relevant in this module are solutions and electrochemistry, which can be downloaded in PDF. Chemical energetics and thermodynamics of equilibrium make useful reading.

Useful Link #3

Title : Experiments On Surface Phenomena And Colloids

URL: http://www.funscience.com

Screen capture :



Solutions and Chemical Reactions

This page begins the attempt of this author to offer some notes that have previously been found either on a chalkboard or an overhead projector. If you find that the notes offer a clear understanding of the underlying concepts, then this Web complex will have been worth it. Please send me e-mail if you have any suggestions or comments. If you click on an option and it doesn't connect, it is probably because that page is under heavy construction and is unavailable at the time. Try again later!!

Most chemical reactions occur in some form of solution. Many of them occur in aqueous solution where water is the solvent (dissolving medium). Indeed our bodies are mostly water by mass, and our planet on which we live has two thirds of its surface covered by water. Since water and solutions of water play such an important part of our chemical world, it is important to investigate the properties of solutions which is the focus of this unit.

Click one of the following:

Concepts To Check		
Introduction to Solutions	Concentration Units	Electrolytes and Non-Electrolytes
Colligative Properties of Solutions	Return to General Chemistry Menu	Return to Home Page

Description: Basics chemistry concepts relating to solutions are presented in table form at this site. These include concentration and colligative properties.

Rationale: This links is useful for quick revision of fundamentals of solution chemistry. It worth reading prior to studying the topic solutions in Unit I.

Useful Link #4

Title: Fun Science Gallery

URL : http://www.funsci.com/fun3_en/exper2/exper2.htm

Screen capture :

© Fun Science Gallery http://www.funsci.com/ giocar2@funsci.com

EXPERIMENTS ON

SURFACE PHENOMENA AND COLLOIDS

Giorgio Carboni, march 2002

Translation edited by G.L. Stuart

Description: The site presents the surface phenomena and colloids with vivid colourful images. Several experiments are interspaced on the site. The details of experiments are hyperlinked for the illustration. The experiments are not only fun but simple to carryout using materials available in the home.

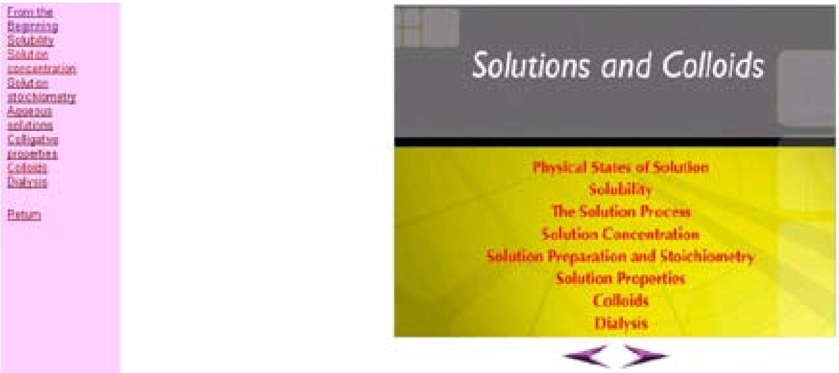
Rationale: Colloid properties are mainly related to the large surface area of the particles. This site helps the learner appreciate some aspects of the surface phenonomena. The site is particularly useful for Unit II which deals with colloids.

Useful Link # 5

Title : Chemistry

URL : http://www.public.asu.edu/~jpbirk/

Screen capture :



Solutions and Colloids

Physical States of Solution
Solubility
The Solution Process
Solution Concentration
Solution Preparation and Stoichiometry
Solution Properties
Colloids
Dialysis

Description: The site presents a series of slides on solutions and colloids. Topics are given in form a Table of contents for easy access to topics.

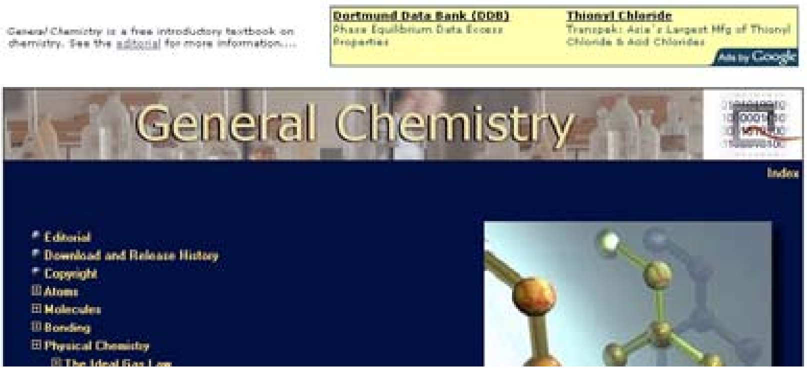
Rationale: The series of slides enable the learner to proceed through Unit II material in stepwsie measured manner. The site has links for animations for illustration of concepts.

Useful Link # 6

Title : General Chemistry

URL: http://www.vias.org/genchem/wrapnt_phase_equilibrium_and_intermolecular_interactions74.html

Screen capture :



General Chemistry is a free introductory textbook on chemistry. See the editorial for more information....

Dortmund Data Bank (DDB)
Phase Equilibrium Data Excess Properties

Thionyl Chloride
Transpek: Asia's Largest Mfg of Thionyl Chloride & Acid Chlorides

Description: This link is to an online General chemistry textbook that operates under the create commons license. Carry a number of topics related to dynamic and phase equilibrium. The learning material is presented in brief concise manner. Reading materials can be downloaded or studied online.

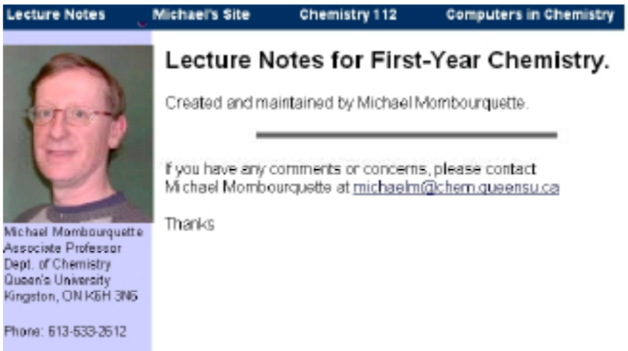
Rationale: The material found on this site is most suitable for the Unit on phase equilibria. Other relevant topics include energetics of chemical reactions and free energy. Aspects of spontaneous mixing is also covered.

Useful Link # 7

Title : Lecture Notes For First-year Chemistry

URL: http://www.chem.queensu.ca/people/faculty/mombourquette/firstyrchem/electro/index.htm

Screen capture :



Lecture Notes for First-Year Chemistry.

Created and maintained by Michael Mombourquette.

If you have any comments or concerns, please contact
Michael Mombourquette at michaelm@chem.queensu.ca

Thanks

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Phone: 613-533-2612

Description: This very useful site has pull down menu to access various general chemistry topics. The learning material is presented in lecture form. The site also has a good section on computers in chemistry which has topics ranging from hardware, operating systems to excel and graphing techniques.

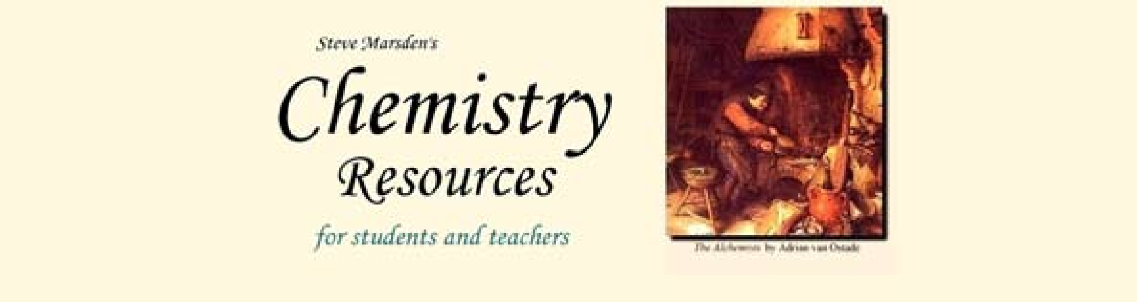
Rationale: This is good one point stop to access a number of learning materials suitable for nearly all the Units in the module. Additionally, the section on use of computers in chemistry allows the learner gain information on software packages for data processing.

Useful Link # 8

Title : Chemistry Resources

URL : http://www.chemtopics.com/index.html

Screen capture :



Steve Marsden's

Chemistry Resources

for students and teachers

The Alchemists by Adrian van Ostade

Description: This Site contains a number of online lectures that are in slide form. The slides can be viewed sequentially or one can hope from one topic to another. Various demonstrations and practice quizzes are provided on the site.

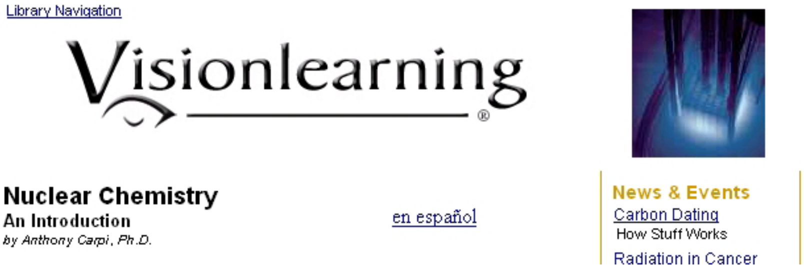
Rationale: Lectures, practice problems and experiments are found on the site that are relevant to Unit IV and V of the module. Some quizzes are accompanied with answer, which enables the learner monitor their conceptual understanding of the subjects. The required multimedia software can be downloaded from the links provided.

Useful Link # 9

Title : Visionlearning

URL : http://www.visionlearning.com/library/module_viewer.php?mid=59

Screen capture :



Library Navigation

Visionlearning®

Nuclear Chemistry

An Introduction

by Anthony Carpi, Ph.D.

en español

News & Events

Carbon Dating

How Stuff Works

Radiation in Cancer

Description: This is essentially a brief discussion of the nuclear chemistry. The fundamental processes and particles are discussed together with the radioactive decay law. The site has good illustrations of nuclear fission and fusion which can be activated

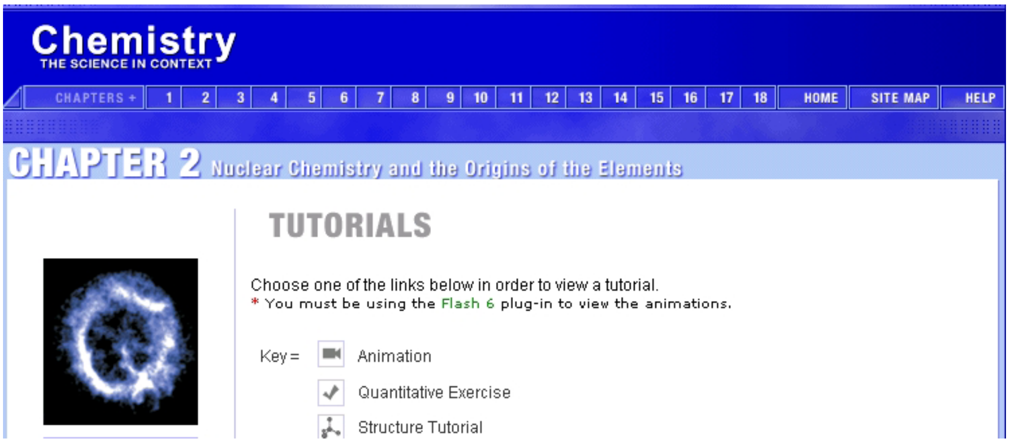
Rationale: Covers nuclear chemistry in very brief manner but has good simulations of the nuclear process which helps the learners understanding.

Useful Link # 10

Title : Chemistry The Concept

URL : http://www2.wwnorton.com/college/chemistry/gilbert/tutorials/ch2.htm

Screen capture :



Choose one of the links below in order to view a tutorial.

* You must be using the Flash 6 plug-in to view the animations.

Key = Animation

Quantitative Exercise

Structure Tutorial

Description: This resource covers various concepts of chemistry in chapters. The materials include tutorials and animations that help visualise dynamic processes. The learner comes across tutorials as one goes through the resources but they can be accessed directly.

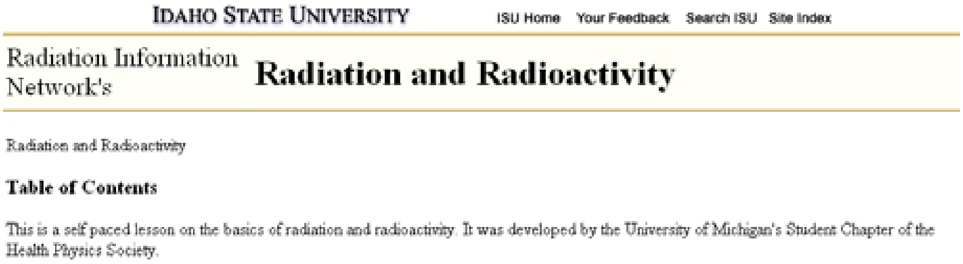
Rationale: The learning material found on this website provides both good backgrounds prior to tackling the module but also supplements new material that shall be encountered in Units IV and V.

Useful Link # 11

Title : RAdiation And Radioactivity

URL: http://www.physics.isu.edu/radinf/cover.htm

Screen capture:



Radiation Information Network's **Radiation and Radioactivity**

Radiation and Radioactivity

Table of Contents

This is a self paced lesson on the basics of radiation and radioactivity. It was developed by the University of Michigan's Student Chapter of the Health Physics Society.

Description: The resources is designed to take the learner through a self-paced study of radioactivity. Besides looking at the fundamental theory it also examines the measurement of radioactivity. Links for related sites are found one the site.

Rationale: The resource provides additional insight to elements of radioactivity as covered in Unit V. It broaden the learners perspective through the links under sources of information such radiation risks and radiation around us.

XV. Synthesis of the Module

This module has covered five major topics: solutions and colloids, phase equilibrium, electrochemistry and nuclear chemistry. In solutions, we have examined the behaviour of homogenous mixtures involving pure substances. You have learned that in the formation of a solution the enthalpy change plays a role in the solution process but that the driving force is the increase in disorder of the system. The ideal solution has been described as one in which the enthalpy change is zero i.e. the intermolecular forces for solute and solvent are alike. Solution properties that are influenced by the magnitude of solute and not its nature – colligative properties such as osmosis, boiling point elevation, and freezing point depression were studied.

Colloidal systems have been discussed and the distinction made from solutions only terms of sizes of the solute. Stability of the systems requires that the particle size remain within the colloidal range. The large surface area of the particles primarily influences properties of colloids. In phase equilibrium, we looked at the physical transformation of pure substances. The concept of phase diagram is introduced as means of following changes that take place when mixtures are heated or cooled. The phase rule is introduced to determine the number of variables that can be changed independently while remaining in the same phase. Systems that involve movement of matter at interfaces are discussed in Unit IV. Under what conditions does a reaction involving electron transfer occur spontaneously? Are questioned and answered in electrochemistry. The relationship between the cell potential and concentration is established through the Nerst equation. The radioactivity phenomenon, where nuclei of certain isotopes undergo spontaneous decay emitting ionising and non-ionisation radiation were also studied. The nature of the different interactions with matter of the various types of radiation were established and the risks arising from such interactions evaluated.

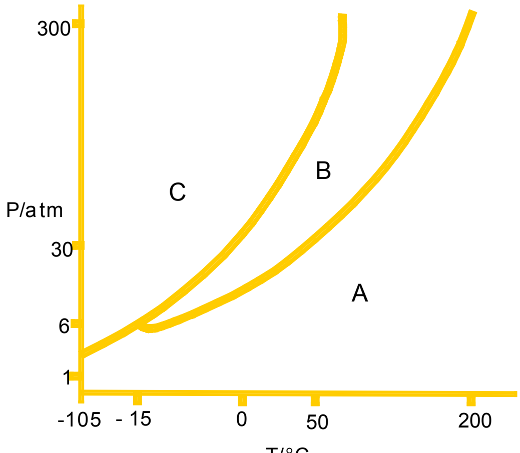
XVI. Summative Evaluation

1. A 50.0 g sample of naphthalene (a nonvolatile nonelectrolyte), $C_{10}H_8$, is dissolved in 100.0 g of benzene, C_6H_6, at 20oC. The vapor pressure of pure benzene is 74.6 torr at 20 °C. Calculate the vapor pressure of the solution. (Atomic weights: C = 12.01, H = 1.008).
   (a) 58.8
   (b) 60.2
   (c) 59.4
   (d) 60.8
   (e) 57.2

2. A solution of 1.00 g of benzene, C_6H_6, in 80.00 g of cyclohexane, C_6H_{12}, reduces the freezing point of cyclohexane from 6.5 to 3.3°C. What is the value of K_f for cyclohexane. (Atomic weights: C = 12.01, H = 1.008).
   (a) -20 °C/m
   (b) -14 °C/m
   (c) -16 °C/m
   (d) -18 °C /m

3. A biochemist isolated a new protein and determined its molar mass by osmotic pressure measurements. She used 0.270 g of the protein in 50.0 mL of solution and observed an osmotic pressure of 3.86 mm of Hg for this solution at 25 °C. What is the molar mass of the new protein?
   (a) 24, 980
   (b) 25,980
   (c) 28, 980
   (d) 29, 000

The questions that follow are based on the phase diagram below of a hypothetical substance.



4. What is the boiling point of the substance at 30 atm pressure?

   (a) 0 °C
   (b) -15 ºC
   (c) 50 ºC
   (d) -105 ºC

5. What type of phase change occurs in moving from B to C?

   (a) Vaporization
   (b) Sublimation
   (c) Freezing
   (d) Melting

6. At what temperature does the triple point occur for the substance?

   (a) -15 ºC and 1 atmosphere
   (b) 0 ºC and 6 atmospheres
   (c) 200 ºC and 300 atmospheres
   (d) - 15 ºC and 6 atmospheres

7. In what form would the substance exist at standard temperature and pressure?

   (a) a gas only
   (b) a solid only
   (c) a liquid only
   (d) a solid or a gas

8. If the standard potentials for the couples A+/A, B+/B, C+/C are +2.0V, +1.0V, and - 0.5V respectively, which is the strongest reducing agent?

   (a) C
   (b) B+.
   (c) C+
   (d) A+

9. If the standard emf of the following cell is 0.91V, what is the standard potential of the Zn/Zn^{2+} electrode? Zn(s)| Zn^{2+} (aq) || H^+, H_2 (aq)| Pt(s)

   (a) 0.91V
   (b) -0.91V

(c) 0.09V
(d) -0.09V

10. If the standard emf of the following cell is 0.91V, what is the standard potential of the H^+/H_2 electrode?

(a) -0.91V
(b) 0.09V
(c) -0.09V
(d) 0 V

11. The standard voltage of the cell A(s) | AB(s) | B-(aq) || C+(aq) | C(s) is 0.1V at 25 Celsius. What is the equilibrium constant?

(a) 12
(b) 36
(c) 49
(d) 52

12 In how many days will a 12-gram sample of decay, leaving a total of 1.5 grams of the original isotope? (The half-life of is 8.07 days)

(a) 8
(b) 16
(c) 20.
(d) 24

13. Given the nuclear reaction:

$$^{12}_{4}\mathrm{Be} + \mathrm{X} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{1}_{0}\mathrm{n}$$

What is the identity of particle X?

(a) alpha particle

(b) beta particle
(c) proton
(d) neutron

14. Given the correctly balanced nuclear equation:

$$^{12}_{6}\mathrm{C} + {}^{249}_{98}\mathrm{Cf} \rightarrow {}^{257}_{104}\mathrm{Unq} + 4\mathrm{X}$$

which particle is represented by the “X”?

(a) $^{1}_{1}H$

(b) $^{1}_{0}n$

(c) $^{4}_{2}\mathrm{He}$

(d) $^{0}_{-1}\mathrm{n}$

15. $^{67}_{31}\mathrm{Ga}$ is used in nuclear medicine to determine blood flow when coronary artery disease is suspected. If after treatment the initial radioactivity of a person’s blood is 20,000 counts per minute, how much time would have elapse in order for the activity to decreases to 4066 counts per minute?

(a) 67 hours
(b) 60 hours
(c) 154 hours
(d) 28 days

Answer key

1. (e) 57.2
2. (a) -20 °C/m
3. (d) 25,980
4. (c) 50 ºC
5. (c) Freezing
6. (d) - 15 ºC and 6 atmospheres
7. (a) a gas only
8. (a) C
9. (b) -0.91V
10. (d) 0 V
11. (c) 49
12. (d) 24
13. (a) alpha particle
14. (b) $^{1}_{0}n$
15. (c) 154 hours

XVII. References

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Petrucci, R. H and Harwood, W. S. (1997). General chemistry: principles and modern applications. New Jersey: Prentice-Hall International.

Animation and simulations Credits

Breenbowe, T. Chemistry Experiment Simulations and Conceptual Computer Animations, Chemical Education Research Group, Department of Chemistry, 3051 Gilman Hall, Iowa State University. http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/simDownload/index4.html#kinetics

Sciencebuddies

http://www.sciencebuddies.org/mentoring/project_ideas/home_Chem.

shtml?from=Home

XVIII. Student Records

Name of the EXCEL file: My Records

Distribution of Marks

Mode of Assessment Marks	Marks
Assignments/quizzes	5 %
Practicals/exercises	15 %
Tests	20 %
Final examination	60 %

XIX. Main Author of the Module

Dr Onesmus Munyati is a lecturer in the Department of Chemistry at the University of Zambia, Zambia. He holds BSc degree in chemistry obtained from the University of Zambia in 1989, MSc and PhD in polymer science and technology from UMIST, UK. I am also the author of a related module Physical chemistry 1 which you may have covered. I hope that your journey through this module has been a pleasurable one. Please send me any comments and suggestions that can improve the module. Contact: omunyati@natci.unza.zm.